BRITISH WELDING JOURNAL

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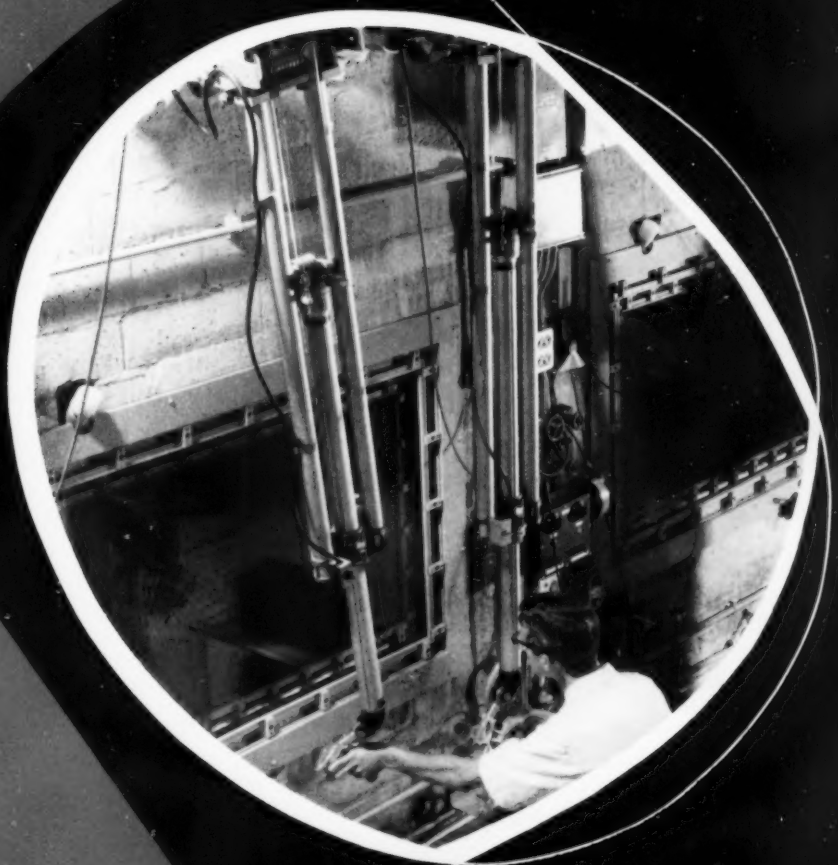

CONTENTS

Welding and Design of Ships
By W. G. Johns

Brazing of Aluminium and its Alloys
By P. F. Woods

Welding of Zinc-Deoxidized Copper
By K. J. Clews

Theory of Cracking in Welds
By J. C. Borland

Discussion—Fatigue of Welded Structures

Cover Illustration
see p. 537

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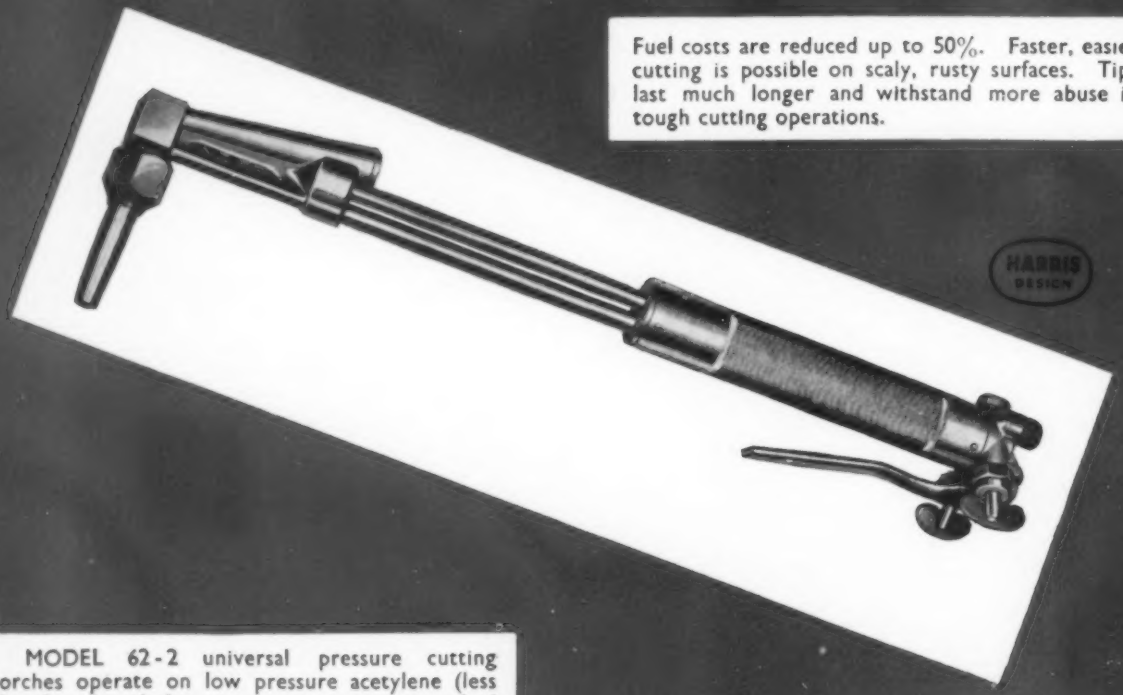

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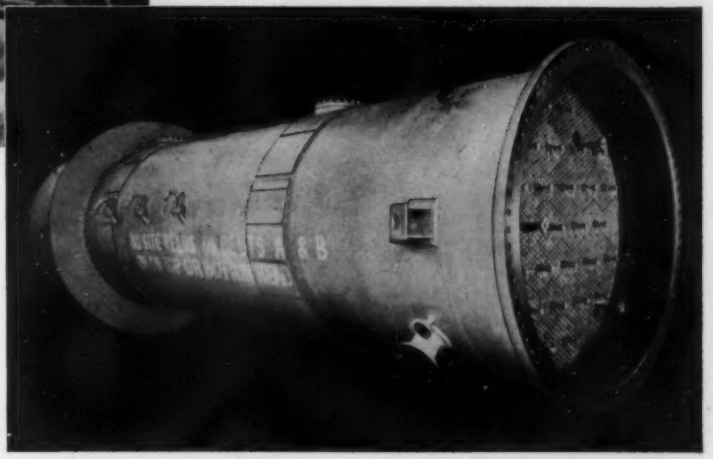

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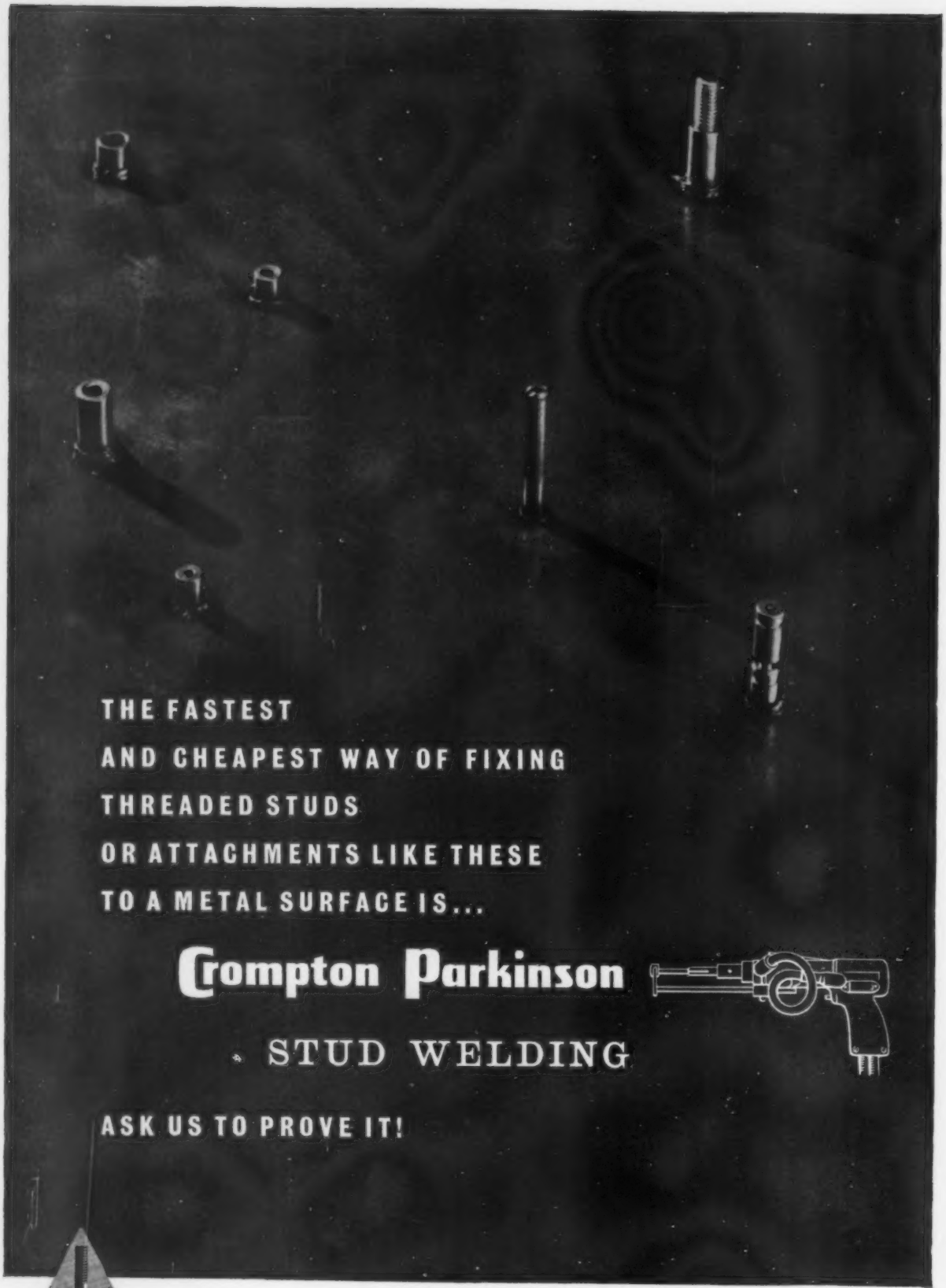
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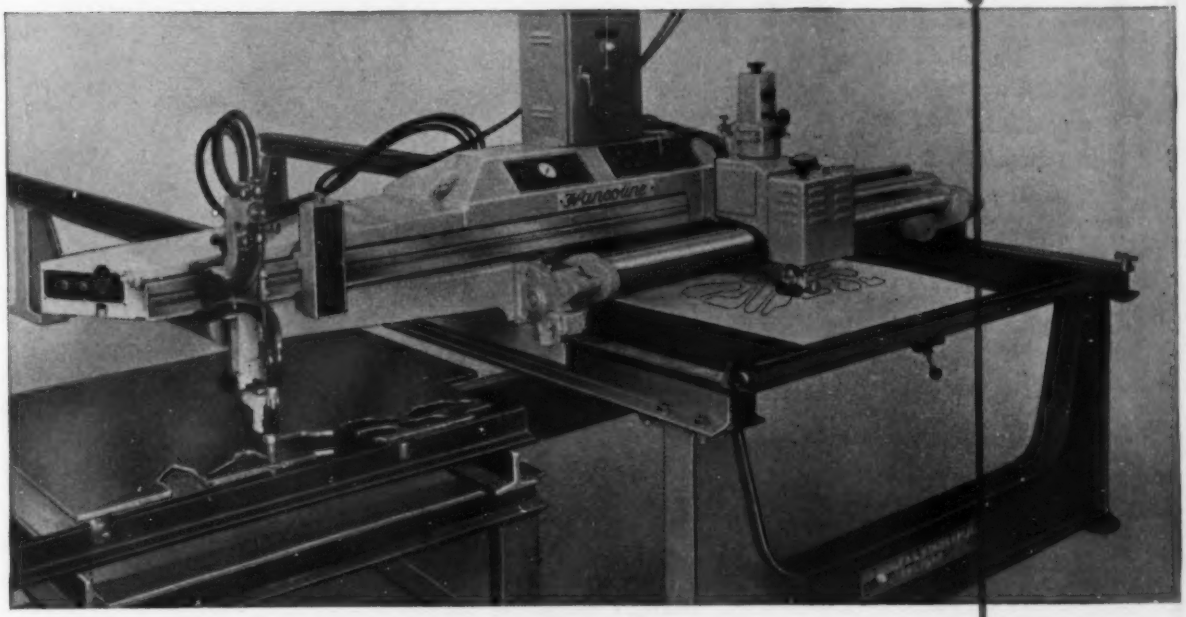

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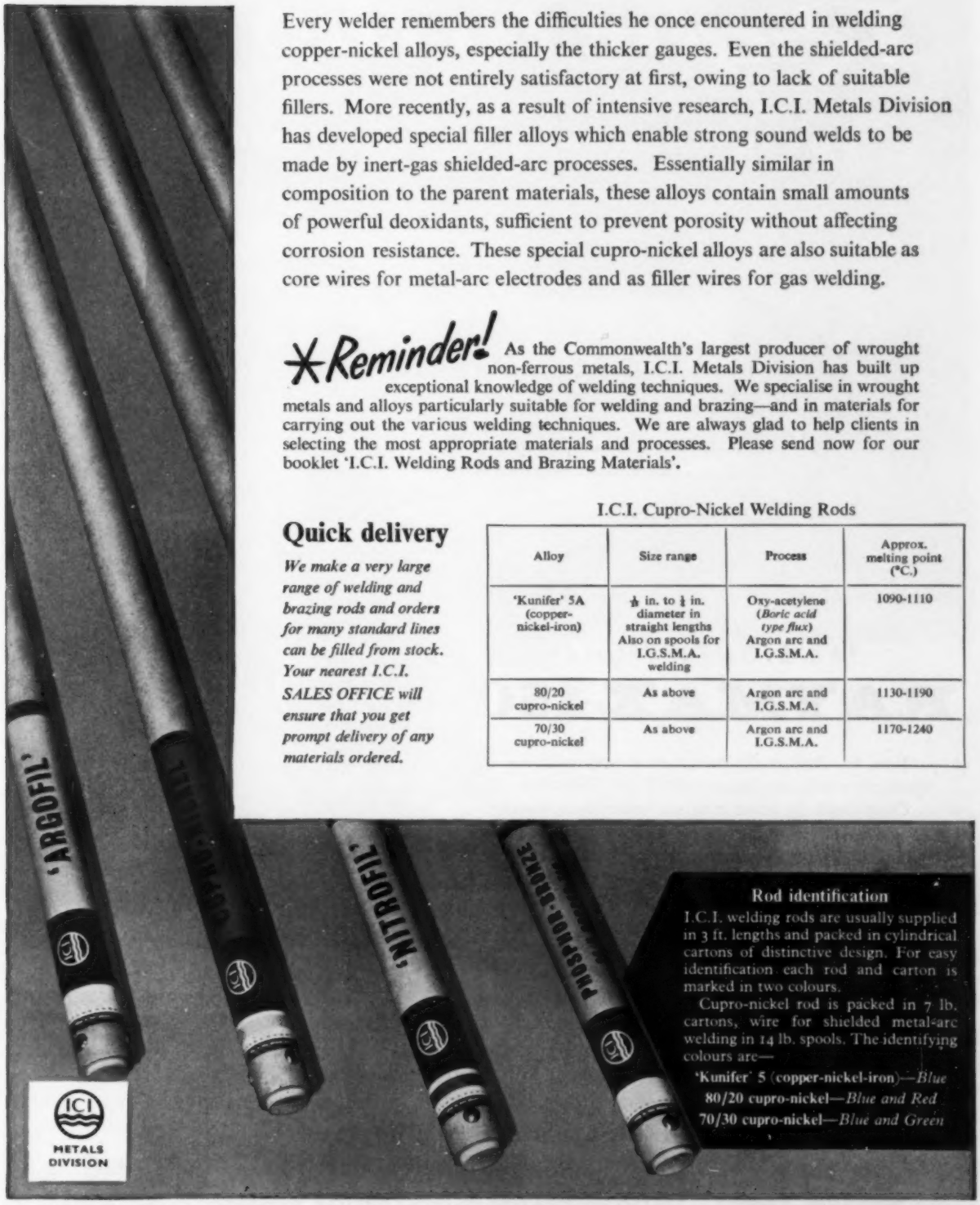
80/20 cupro-nickel	As above	Argon arc and I.G.S.M.A.	1130-1190
70/30 cupro-nickel	As above	Argon arc and I.G.S.M.A.	1170-1240



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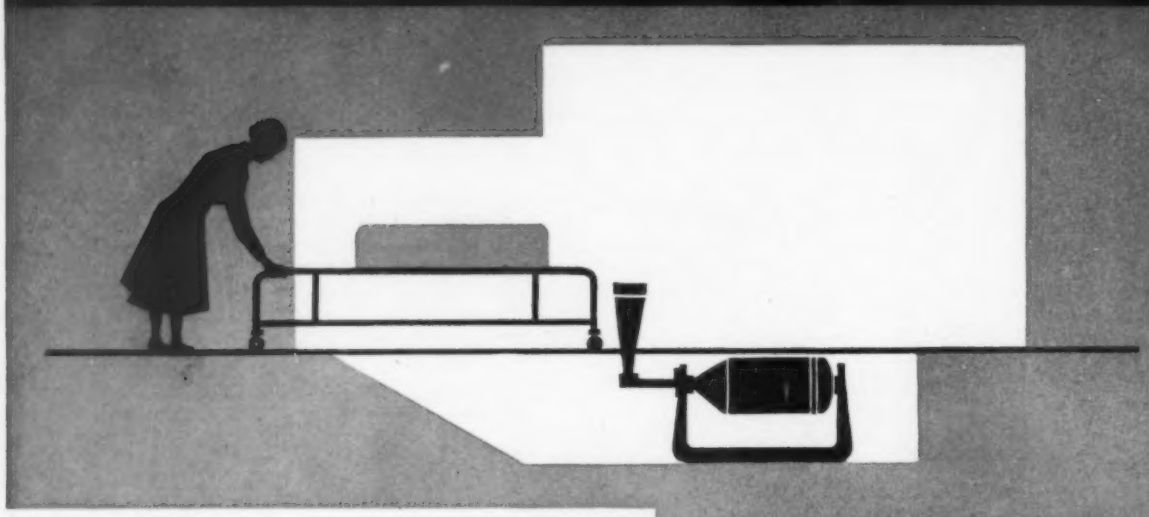

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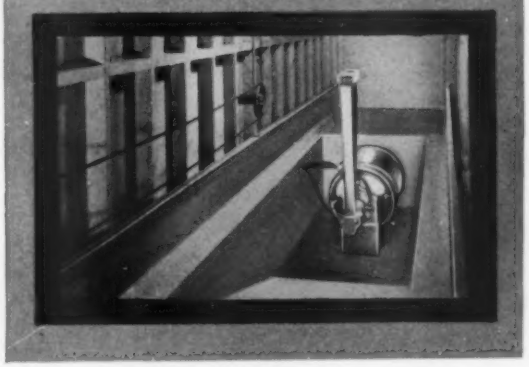

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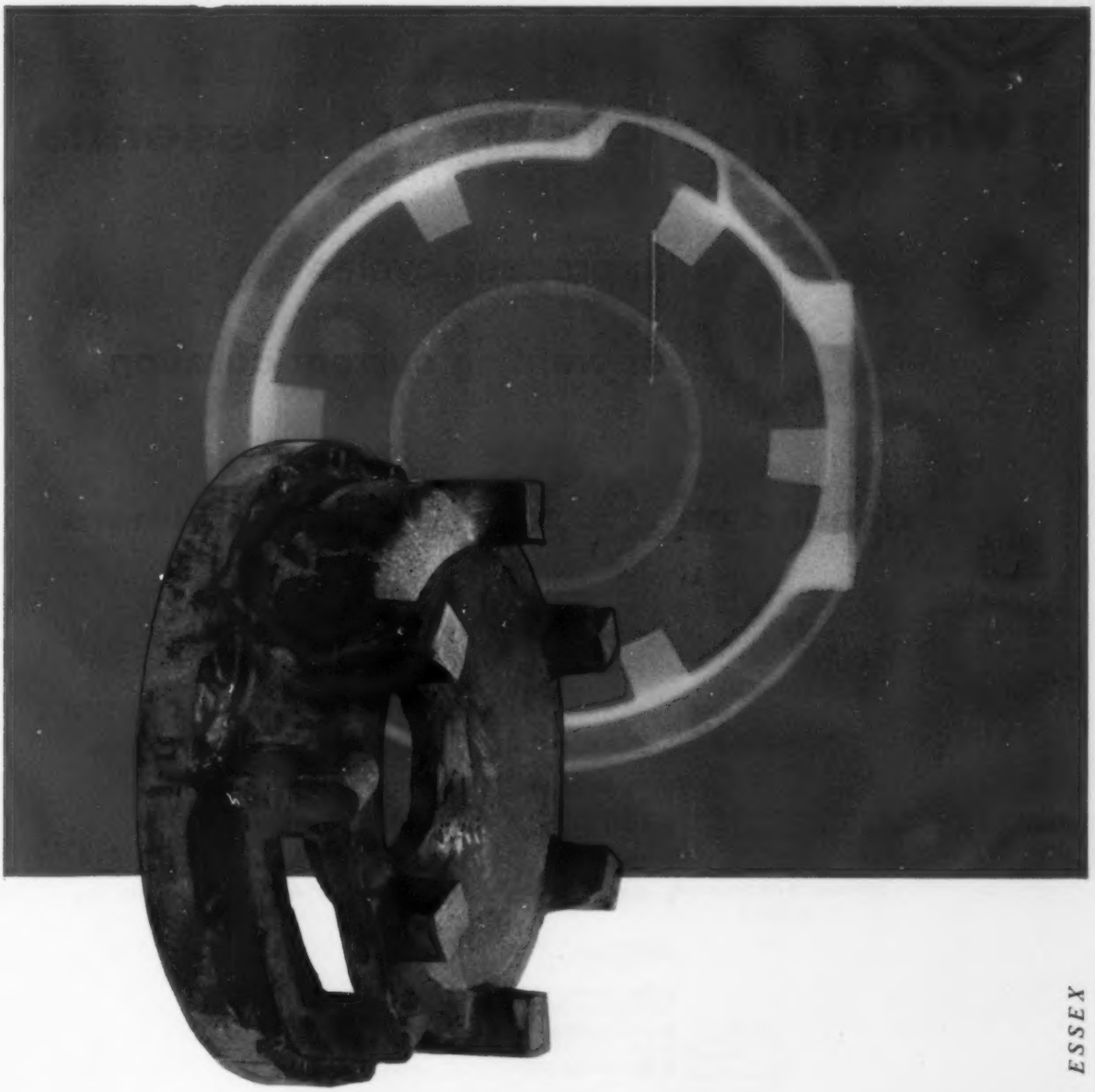

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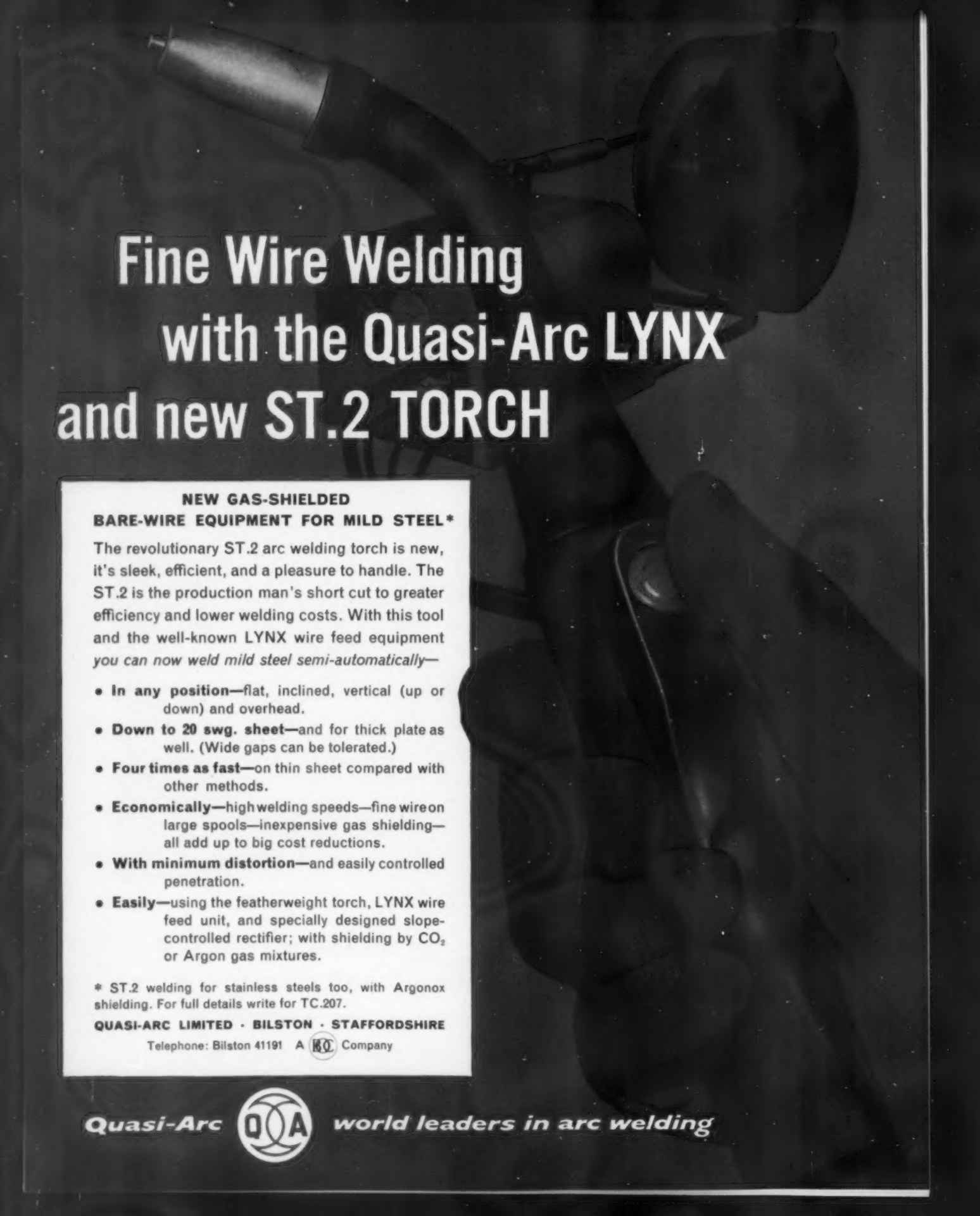

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CONTENTS

INSTITUTE OF WELDING

489 **Brazing of Aluminium and its Alloys with Air/Propane** *By P. F. Woods*

491 **3rd Annual Lecture—Influence of Welding on the Design of Ships** *By W. G. John*

BRITISH WELDING RESEARCH ASSOCIATION

503 **Autogenous Argonarc Welding of Zinc-Deoxidized Copper** *By K. J. Clews*

508 **Generalized Theory of Super-Solidus Cracking in Welds (and Castings)** *By J. C. Borland*

513 **Discussion at the Symposium on Fatigue of Welded Structures**

530 NEWS AND ANNOUNCEMENTS

539 CURRENT WELDING LITERATURE

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Welding
TECHNOLOGY

A Note on the Brazing of Aluminium and its Alloys with Air/Propane

This note describes a method of overcoming difficulties in the flame brazing of thin aluminium alloys, by the use of a propane-air torch. A typical application is illustrated.

By P. F. Woods

THE accepted medium for the flame brazing of light alloys is the oxy-acetylene torch. Sometimes, the oxy-hydrogen flame,[1] with a temperature of 2200°C., is used although the oxy-acetylene flame[2] can reach a temperature of 3100°–3300°C.

For general purposes these processes are quite satisfactory for the brazing of light gauge material containing up to 2% Mg, but the intense heat of the oxy-acetylene flame is often a distinct disadvantage. The propane-air flame, on the other hand, has a temperature of 1400°C., and this would appear to make it a more suitable tool for light-alloy brazing.

Alloys of aluminium containing more than 2% Mg are not suitable for flame brazing because of the formation of magnesium oxide, which encloses the braze in a tenacious, flux-resistant film and so prevents the alloy from flowing freely into the joint. This oxide, which forms readily at normal temperatures, is produced even more rapidly at the elevated temperature of brazing. This factor is an additional disadvantage when light gauge fabrications are to be brazed with the oxy-acetylene process.

Although skilful manipulation of the torch can undoubtedly help, the necessary skilled operators are not always readily available. The use of the propane-air process for the successful flame brazing of aluminium and its alloys is therefore more acceptable to the average welder, as distinct from the specialist operator.

The lower temperature of the propane-air flame provides a slow soaking heat, which means that the material is brought uniformly to the brazing temperature. With the oxy-acetylene flame the surface of the material reaches brazing heat before the main mass of metal, so that the brazing alloy is more reluctant to flow by capillary action between the interfaces of the joint.

The outer envelope of the propane-air flame is reducing, like the neutral oxy-acetylene flame, but it has the advantage of a larger cross-sectional area which helps to protect a greater area of the working surfaces

Manuscript received 27th November 1959.
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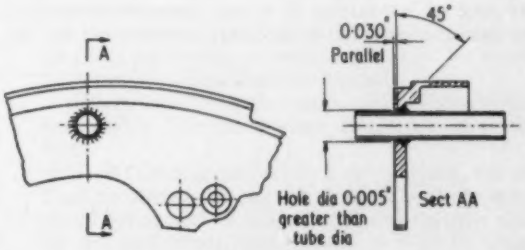
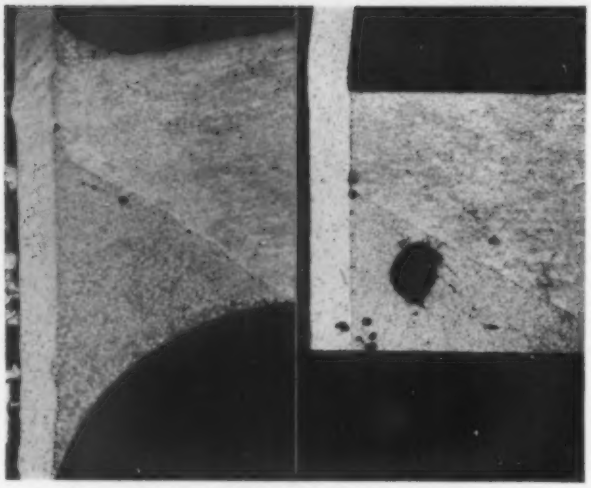


1—*Diagram of part of brazed assembly*



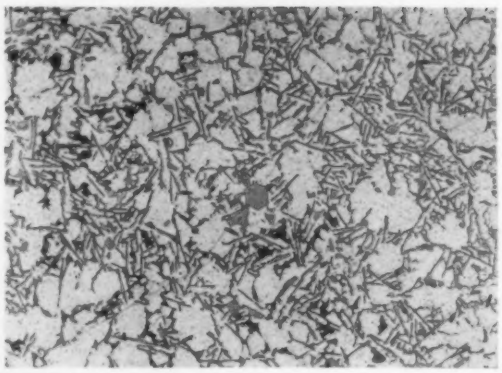
(a) (b)

2—*Aluminium alloy brazed joint:* (a) *Oxy-acetylene flame;* (b) *propane-air flame (etched Kellers reagent)* ×20

from atmospheric contamination. Also, the slower heat input over a larger surface, facilitates wetting by the brazing alloy, as well as retarding the formation of magnesium oxide. Since the oxide is produced in greater amount with higher temperature (as with the oxy-acetylene flame) a point is reached where the flux becomes ineffectual. The refractory nature of the oxide, which has a melting point of 2800°C., and the inability of the flux to remove it, can therefore be quite a problem. The temptation to increase the heat input inevitably results in severe distortion or even collapse of the parent material. With the use of the propane-air flame this danger is remote.

Although rapid oscillation of the oxy-acetylene torch is needed to prevent overheating, it is detrimental because it exposes a series of heated areas to oxide contamination before the flux is available or brazing commences. Conversely, the propane-air torch can be held steadily over the bonding zone, and its large reducing flame gives adequate protection to the work surfaces.

Butane is another of the liquid hydro-carbon by-products of the fractional distillation of heavy petroleum-bearing oil, but its flame temperature, with oxygen, (3000°C.) is higher than that of propane with oxygen (2600°C.), and its volatilization rate is less. A mixture of coal gas and air, whilst producing a similar temperature to that of propane-air, is not so effective as a brazing medium because of the possible presence of impurities. It would therefore seem that the propane-air torch is the most suitable tool for the



3—*Microstructure of brazed joint, showing primary and eutectic silicon (etched Kellers reagent)* ×200
(micrographs reduced × ½ linear in reproduction)

low-temperature flame brazing of aluminium and its alloys, and its use should be seriously considered for light gauge assemblies, particularly where thick and thin sections of alloy material have to be joined.

An example of such an application is illustrated by the accompanying micrographs. Figure 1 shows part of an assembly consisting of a section of $\frac{3}{8}$ in. o/d tube with a wall thickness of 0·022 in., which had to be attached to a complex angle section $1\frac{1}{4} \times 1\frac{1}{8}$ in. and 0·206 in. thick at the position of the joint. The tube was made from BS.L56 alloy, containing 2% Mg, and the flange was a proprietary alloy containing 6% Cu and 1% Ni.

The joint clearance between the two components was 0·005 in., and the top side of the flange was bevelled to 45° with a 0·030 in. root face. The tube protruded $\frac{1}{2}$ in. above the surface, the surplus being eventually machined off.

The filler wire was a $\frac{1}{8}$ in. dia. aluminium alloy containing 10% Si and 4% Cu, in accordance with BS.1942 : 1953, Type 1.

Sections of joints made with the oxy-acetylene and the propane-air flames are shown in Figs. 2 and 3. Whilst porosity and indifferent surface bonding is shown in the oxy-acetylene braze (Fig. 2*a*) only micro-porosity is apparent in the propane-air brazed sample. The complete penetration of the joint as illustrated in Fig. 2*b* is a normal feature of the propane-air process, and the parent metal shows no sign of overheating or thermal disturbance.

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THIRD ANNUAL LECTURE

The Influence of Welding on the Design of Ships

By W. G. John, R.C.N.C., M.R.I.N.A.

THE development and application of welding techniques has had a most profound influence on every field of structural and engineering work and their resulting products. For items such as pressure vessels, nuclear reactors, and gas turbines, modern production would not be practicable if welding techniques were not available for the jointing of the materials of which they are made. It may not be generally appreciated that the application of welding processes has had a revolutionary effect on both the design and production of ships and that, apart from the pioneering work, the changes have come about in the last 20 years or so.

The Second World War saw history made in the application of welding to ships, both in Britain and in the U.S.A. It was in 1942 that the Admiralty advised all shipbuilding firms that, after full consideration of the problems and difficulties of ship production at that time, the Admiralty was strongly of the opinion that an increase in output could be achieved by the extension of electric welding in the shipyards. Almost every shipyard in the country extended the use of welding.

It was not until welded ships had been produced in large numbers, under the U.S.A. war emergency programme of merchant ships, that the possible *disadvantages* of large-scale welding became apparent. The U.S. experience of welded ship fractures stimulated much research into the differences between the behaviour of welded and riveted vessels. Much of the work of the U.S. Board of Investigation,[1] the U.S. Ship Structure Committee,[2] and the Admiralty Ship Welding Committee,[3] followed by the Admiralty Advisory Committee on Structural Steel, stemmed from these experiences.

As late as 1947, the *Transactions* of the Institute of Welding reported a special meeting, organized by the Institute, to discuss the subject "Future Ships: Will they be All-Welded?"

However, despite all the problems of design; the measure of uncertainty arising from failures with the early welded ships, and the reluctance of customers to change from specifications proved by experience; the difficulties associated with the adaptation of shipyards originally laid out for riveting, and with drawing office staffs trained in techniques to match the yard layouts; the welded ship has now become normal for both the warship and commercial fleets.

Reference to the rules of Lloyd's Register of Shipping shows that the 1949 Rules were mainly based on the concept of riveted construction, with suitable modification clauses to be applied for welded ships. Now the latest Lloyd's rules are based on welded ship construction with some references to riveting, and in a paper presented in 1955 Murray[4] refers to the changes in structural design and shipbuilding methods resulting from the introduction of this method of construction.

To deal with this tremendous change-over, shipbuilding firms have spent many millions in rearranging the building yards, equipping new workshops, and providing new lifting and transporting facilities to the building slips and fitting-out berths. Shipbuilding has become a more closely organized business, and all the work from design and drawing offices to the completed ship has become more precise and accurate.

Advantages of a Welded Structure

The advantages of a welded ship structure can be summarized as:

(i) Appreciable weight economy due to the savings on overlapped edges, butt straps, faying flanges, and brackets which are necessary in riveted joints to provide space to accommodate a sufficient number of rivets. Ships exist to carry loads of one kind or another, so that as compared with its riveted counterpart, a welded ship can either carry a greater load, or be faster or carry more fuel to travel a greater distance.

Alternatively, for a specified load, speed, and range of operation, a welded ship can be smaller and cheaper to run than the riveted.

Whichever way the saving is applied, the design is appreciably different in some of its major characteristics.

(ii) Whilst engaged on its load carrying, the ship must be strong and secure to carry both its operational loads and to withstand being thrown about by seas and winds, and it must be built to operate with a minimum of maintenance effort between

The third of the Annual Lectures was delivered at a special meeting of the Institute, held at 54 Princes Gate on Thursday, 3rd March 1960.

Mr. John is Deputy-Director of Naval Construction, Admiralty.

widely spaced refit periods. The welded joints are both more efficient as structural connections and are better able to stand up to damage which may arise from the hazards of both peace and war.

The riveted lap joint is inefficient under direct compression or tension, and even the riveted butt cannot reach the full strength of the intact plate. Symmetrical sections (tee plates, bulb plates) are used for welded structures instead of the less efficient unsymmetrical rolled sections.

(iii) It is much easier to secure oil-tightness and watertightness with welding.

The welded structure's capacity for sustaining appreciable damage without leaking was conclusively shown by war experience. As well as being inherently strong, welded joints can suffer heavy distortion without leaking. On the other hand, riveted joints leak, and rivet heads fly off, even with slight indentations which may arise from impact or shock loadings.

(iv) The whole structure can be more neatly and simply designed, and the fittings can be built-in rather than being stuck on.

Another advantage from the use of welding is the reduction of the frictional resistance of the hull. Whilst the assessment of a precise value for the reduction is still under consideration by our Ship Experiment Tanks, it is clear that there is a worthwhile advantage with a useful reduction in running costs. Fouling and corrosion can prejudice this saving, so that if we are to obtain the full advantage from the welded ship's smooth bottom, it becomes important to give attention to the methods of preparation and coating of the bottom.

Influence on Main and Auxiliary Machinery for Ships

The use of the welding process has facilitated design and manufacture to give a marked improvement of overall efficiency.

The modern boiler with its higher steam pressures and temperatures is smaller and of less weight than its predecessor, and maintenance troubles are reduced, particularly in respect of corrosion of joints and tube-end leakage.

The higher boiler temperatures have led to the use of improved low-alloy thin wall pipe materials (such as 1% Cr–½% Mo steels).

Welded boiler casings permit the air to be fed direct to the boiler so that the boiler room is open and habitability conditions are very much improved.

Fabricated low-pressure turbine cylinders, gear cases, and condenser shells provide more flexibility in design and the elimination of intricate and doubtful quality castings.

The use of high-temperature and corrosion-resistant material is facilitated, *e.g.* in gas turbines.

Welding fabrications are used for the stators of the main electrical generators, giving considerable advantages in respect of weight and of resistance to mechanical shock.

The welding process is of considerable economic value in dealing with repairs and maintenance. Welding repairs to items such as turbines and fire-tube type boilers *in situ* in the ship avoids the heavy cost of removal from the ship and often prolongs the life of a component. Apart from the direct savings on the machinery items, welding often reduces the length of time during which the ship is out of operation for repairs.

The reinforcement of worn bearing surfaces of propeller shafts avoids the premature scrapping of these large and costly items.

Welding repairs to cast steel valves and other castings avoid long-term delivery replacements, and the hard-facing of valve lids and seats reduces wear and maintenance.

Welded pipe systems and fabricated manifolds show a reduction in leakage, and the greater cleanliness of the machinery spaces reduces the maintenance work on the hull structure.

For nuclear propulsion machinery, a fundamental requirement of a power reactor system is that the leakage of the heat transfer vehicle, or fluid, into the surrounding compartment (itself an integral and complete containment) must be *nil*, or as near as to be undetectable. This is to prevent the escape of radioactive corrosion products and fluid, generally, and, in particular, the extremely harmful and long-term fission products, in the event of failure of the fuel element cover-plates. Such conditions can be obtained only by the extensive use of welding.

Submarine Construction

Nuclear propulsion brings to mind H.M.S. *Dreadnought*.

Submarines were the first of the major warships to be all-welded. The introduction of the all-welded pressure hull not only saved weight by the elimination of rivets, butt straps, and the like, but also permitted the adoption of more efficient frame sections with an additional saving in weight. This saving in weight for the same size submarine permitted an appreciable increase in the diving depth, one of a submarine's main features.

The adoption of welding markedly reduced the risks of leaks occurring at rivets, both in normal service and when the vessel was subject to enemy action. This is of particular importance in the case of the oil fuel tanks, where a leak would betray the presence and position of the submarine.

Coming to the fast nuclear propelled submarines, ever deeper diving depths are required, and the weight bonus from welding has been even more essential. In addition, it has been noted that the reactors have to be provided with a containment structure to localize the effects of any untoward nuclear incident. Relatively high pressures may be involved, and the achievement of an extremely low leakage rate involves a standard of tightness unlikely to be attained with anything other than an all-welded structure.

The submarine is a pressure vessel, and in the future we shall need to weld steels of still higher strength than those now being employed. So we shall go on progressing.

Economic Considerations

We have reached the era when welding is being used for all types of ships in the commercial world—passenger liners, tankers, cargo vessels—as well as for

warships. The days have gone when there was doubt about the economic consequences of welding ships in the yards which are organized and equipped for modern work.

In a lecture in 1958, Dr. Ramsay Gebbie[5] brought out the economic advantages to the shipowner in respect of both the initial cost and the running costs of welded cargo ships. Special reference to the passenger liner was made earlier by Redshaw.[6]

Results of Experience with Welded Ships

Some of the main findings of the Admiralty Ship Welding Committee researches may be summarized as follows:

(i) There is no evidence to support the view that elastic behaviour of riveted ships differs materially from that of welded ships because of slip in riveted joints. Hence, the basic design criteria for the longitudinal strength of riveted and welded ships need not differ.

(ii) However, the tendency of rivets to slip at high stresses may alleviate local concentration of stress in way of sudden discontinuities. Hence, the incidence and extent of fractures originating at stress concentrations are likely to be less in riveted than in welded ships. The design of details in way of discontinuities therefore requires much greater care and attention in welded ships.

(iii) The welded structure contains high initial stresses arising during fabrication. Whilst these residual and reaction stresses may not increase the likelihood of crack propagation, they may encourage crack initiation or induce local cracking during or shortly after welding. Such local cracks might eventually precipitate major brittle failures.

As a corollary, welded structures will generally be more distorted during fabrication. This not only affects their appearance but may also induce locally high stresses when initially dished plating is loaded in edge compression. It also raises the possibility of snap-through buckling when dished plating is loaded so as to cause reversal of the dishing.

(iv) Close attention must be paid to the selection of the material in regard to (*a*) its ability to be welded under production conditions without cracking during the process, and (*b*) its 'notch toughness', *i.e.* its resistance to brittle fracture in the presence of a notch effect. These properties become more important and more difficult to attain as either the thickness or the tensile strength of the material is increased.

It is noteworthy that the application of welding as a more efficient method of jointing served to highlight a number of structural problems which, because the riveted joint is tolerant of local overstressing at positions of bad detailed design, had not previously been widely studied. Their consideration has resulted in the more widespread adoption of rational methods of hull construction; *e.g.* the use of continuous longitudinal framing, avoidance of abrupt changes of section and of square corners at deck openings, and better design of bulkhead stiffeners.[7]

However, these considerations were well in the minds of the more advanced ship designers, and the most outstanding new requirement brought into prominence by early welding experience was the need to take every possible precaution to minimize the risks of brittle failure.

Design Methods

So far, the basic design criteria for longitudinal strength remains the same for both riveted and welded ships.

We produce a safe design by using formulae based on the elastic theory, with factors of safety which really represent the result of generations of experience. It is in the application of this experience that a major responsibility of the Naval architect lies.

Structural members are generally independently calculated with assumed degrees of fixity at the ends. Research in other fields has shown that in welded frameworks with rigid joints, use of plastic design methods gives an appreciable saving in weight compared with conventional elastic design methods. The shortcomings of elastic structural design have been stated[8] by Professor Baker, whose team at Cambridge, working closely with B.W.R.A., have led the work on the development of a plastic theory for structures. Whereas elastic analysis enables the designer to calculate the load that will first cause yield to occur in a structure, it is now known that this 'yield load' does not give a true indication of the real strength of the structure, *i.e.* the load that it can withstand without complete collapse.

I have already remarked that a welded structure contains complex residual stresses of unknown magnitude. It is clear that when we superimpose the loadings occurring in service, stress concentrations must arise, and there can be no doubt that there must be local plastic flow in places.

So it may well prove that, subject to the use of satisfactory standard connections between all members of the structure, we may in due course develop methods of plastic design applicable to our highly redundant ship structures, with a resultant further economy of structural weight.

A start has been made on methods of plastic design for ships at the Naval Construction Research Establishment. One of the first steps has been the design of standard welded connections for beams to frames and longitudinals to frames.

Even that other disadvantage of welded construction —greater initial distortion—may ultimately be turned to good account. Recent work by Clarkson[9] has shown that, in plating subjected to lateral pressure, it is advantageous to take account of the fact that plating which has even a slight initial deflection in the direction of applied pressure can withstand a greater pressure without yielding than can a similar perfectly flat plate. Thus, the slight initial distortion almost inevitably present in welded plating may lead to a reduction in plate thickness required to withstand a given pressure.

It is, of course, a nice question of professional judgment how far any particular type of ship should be really 'designed' rather than just built with safe margins. Designing may occasionally lead to troubles, but it does avoid carrying a dead weight margin round the world. This is a very live problem in the warship field.

Effects on Shipyard Organization

As the industry developed the use of welding, it soon became apparent that to reap the advantages to be gained from welded structures, it was necessary to develop a new and more detailed organization through out the whole of the shipyard, and at the same time to start the long-term process of building up a background of knowledge and experience for welding work such as was already in existence for the long-established

working procedures. The change had to start in the drawing office and go on through every stage of the work.

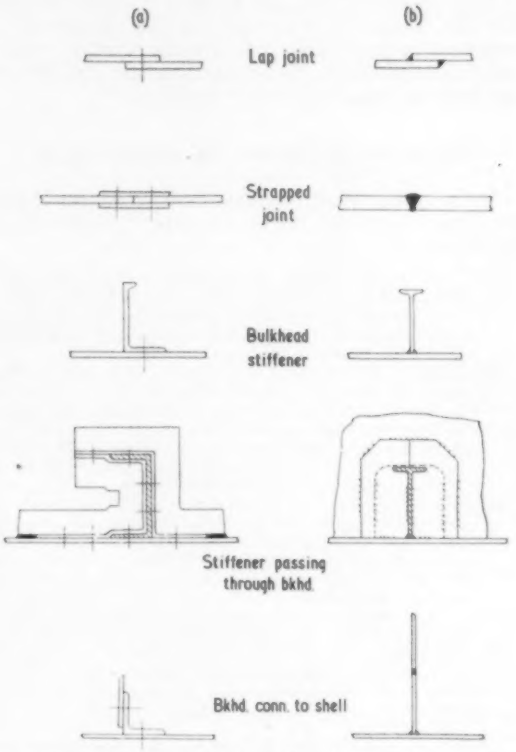
When welding was first introduced into ship structures, the draughtsmen tended to copy the arrangements followed in the conventional riveted work. We are mainly out of this stage and our large prefabricated units are designed so that the welds can be efficiently and economically carried out.

One of the requirements for a welded structure is that drawings must be prepared in detail to include the welding procedures and the prefabrication arrangements, in addition to the details of the scantlings and connections. Distortion is associated with the process, and its control demands the use of specified welding techniques, which include the sequences in which the various welds are to be performed. This greater volume of detailed drawing work is, of course, required to be ready in advance of the actual building.

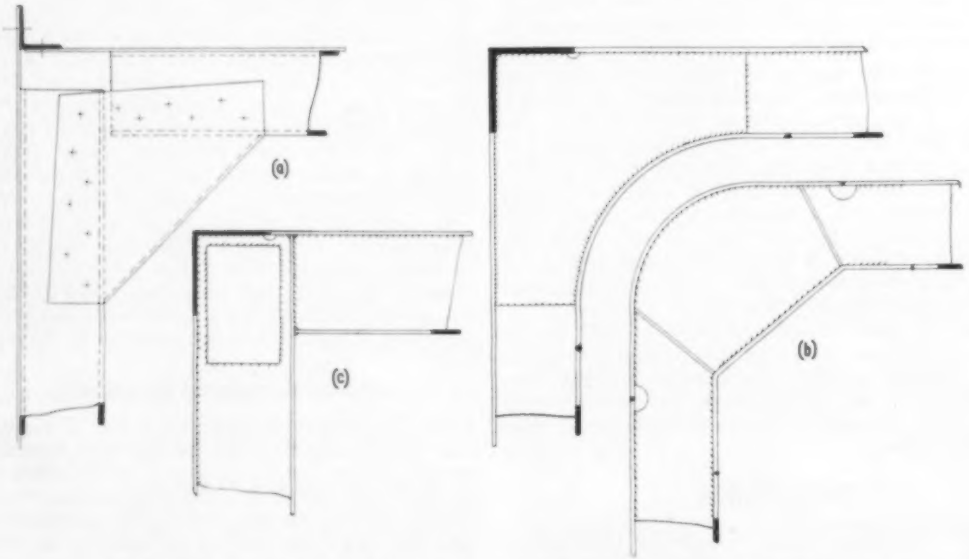
One of the keys to economy is good workmanship, calling for more precise fitting than had been usual for riveted work. If the preparatory work by the other trades does not provide joints in accordance with the specification, quality welding will not be possible. The correction of poor welding can be very costly. Further, the welding has to be carried out, as far as possible, under standardized and controlled conditions, and subject to adequate inspection. The layout and plant equipment of many of our yards have undergone changes that have radically altered both the appearance and the working conditions of the shipyards. Large enclosed prefabrication shops equipped with entirely new plant facilities are a tribute to the progressive attitude of much of the Industry. The new shop facilities are matched with the transporting and crane lifting facilities at the building berths.

The construction of large prefabricated units in workshops has reduced the time required on the building berth, and this has led to a reduction in the number of berths required, although it also calls for a crane-covered lay-apart space for storage of the shop-produced units until it is time for the assembly on the berth.

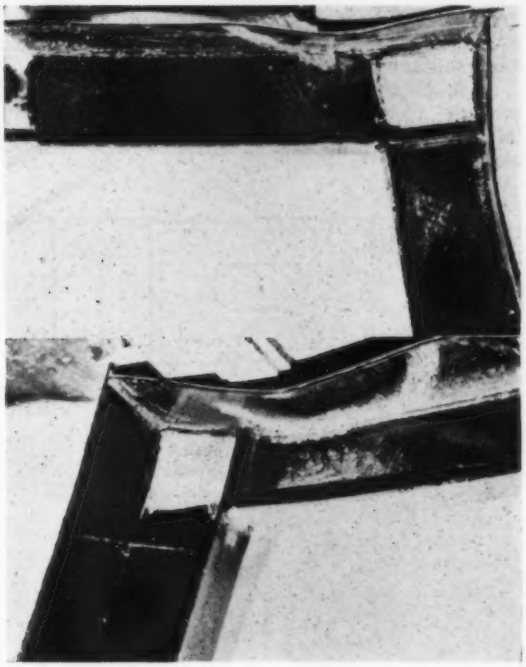
The prefabrications can be produced under working



1—*Comparison between* (a) *riveted and* (b) *welded structural connections*



2—*Beam frame connections:* (a) *Riveted;* (b) *early welded examples;* (c) *present welded example*



3—*Beam frame model after compression test*

conditions equal to the best engineering practice. Whilst it is more difficult to build covered building berths with the necessary lifting equipment, maybe we shall see more of them in the future.

The reduction of noise in the shipyard is another noticeable 'work environment' factor.

Effect on the programme of work

Reference has already been made to the need for more detailed drawings to be prepared ahead of the work in the yard.

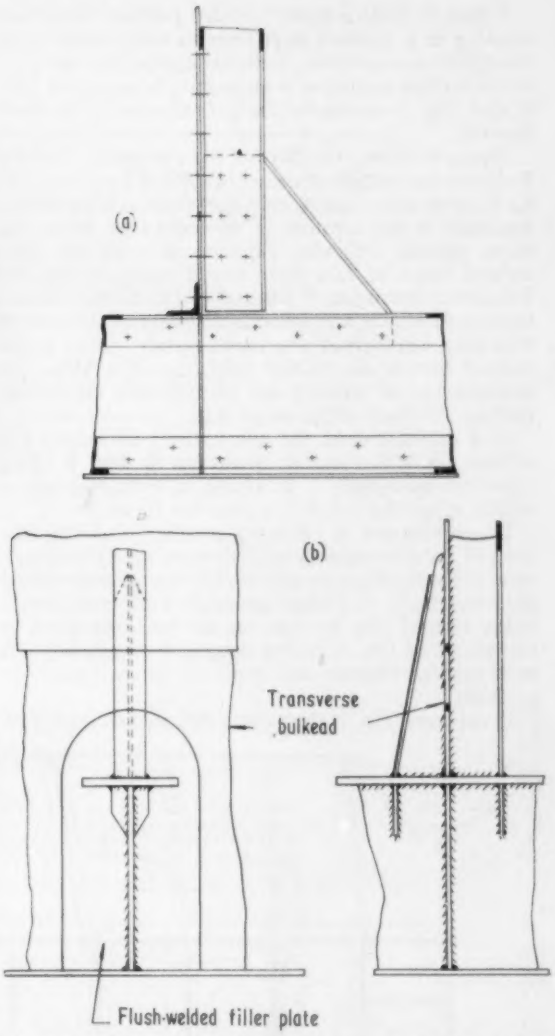
With the development of the prefabricated unit system, it becomes practicable and economical to start fitting out some of them before erection in the berth; *e.g.* the double bottom and tank units with their piping systems. This means that both the design and production of the systems must be undertaken and completed at a considerably earlier stage than has been usual.

Examples of the marked Differences between Welded and Riveted Work

The accompanying illustrations* show that, as a result of the change from riveted to welded construction, the detailed arrangements of the ships structures have taken on a completely new look.

Figure 1 illustrates structural joints in which the welded version is more efficient than the riveted. The beam frame connection now adopted for warship work is shown in Fig. 2. The abolition of bracket plates has obvious advantages in weight economy, and in the freeing of internal space so that stowages are

* Only a selection of the slides shown by Mr. John is reproduced.



4—*Connection between bulkhead stiffener and deep longitudinal girder:* (a) *Riveted;* (b) *welded*

very markedly facilitated. The Admiralty design of bracketless connection is based on experimental work carried out at the Naval Construction Research Establishment with models made from typical rolled sections used in ships, tested both in compression and in tension.

The result of a typical compression test to destruction is shown in Fig. 3. Three of four connections failed at the fillet weld joining the 'beam' flange to the 'frame' flange; but the loads were high, and flaking of the resin coating on the model showed that the beam flange was entirely plastic before failure occurred. The fourth connection failed by buckling of the 'deck plating', and in the three other models, where weld fracture occurred, it was evident that this form of buckling was imminent.

An Admiralty design for the connection between a bulkhead stiffener and a deep longitudinal girder is shown in Fig. 4, compared with its riveted counterpart.

Figure 5 shows a typical welded portion of bottom framing in a modern large liner in comparison with the earlier riveted form. A similar comparison for part of the turbine seating of a large liner is shown in Fig. 6, and Fig. 7 compares the two versions of a shaft bracket.

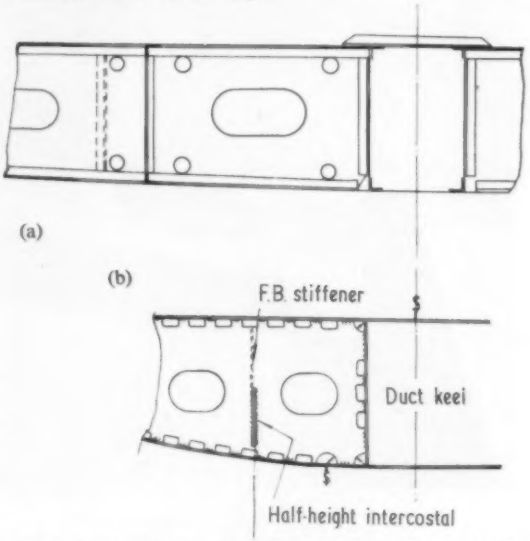
Figure 8 shows the effect of the changes in Lloyd's Rules on the bottom structure of a 470 ft long × 65 ft × 42 ft cargo ship. Apart from the troubles from brittle fractures in the topsides of welded cargo ships, the most serious difficulty experienced with the first welded ships of this type was a tendency for the bottom to corrugate.[10] Instead of the closely spaced transverse frames with a few side girders of the riveted ship (Fig. 8*a*) there is a series of closely spaced longitudinal bars in the welded ship (Fig. 8*b*). Thus, the introduction of welding has transformed the double bottom structure of the cargo ship.

In a different field, the first entirely all-welded destroyer, H.M.S. *Contest*, is shown in Fig. 9 being launched by Messrs J. S. White in 1945. She was a highly successful job with a nice fair form.

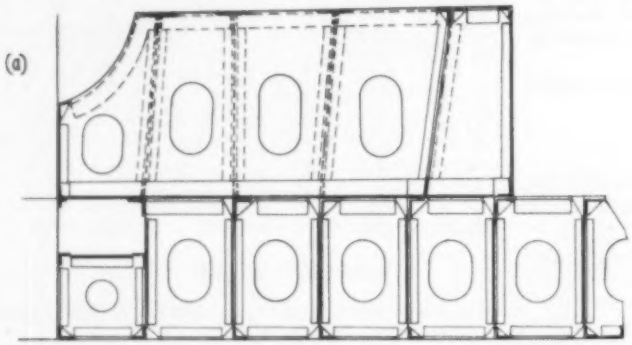
The revolution in shipyard practice, and the new look of the structural detail, is shown up by comparisons of the building procedures for riveted and welded destroyer hulls. A riveted keel with transverse frames being erected one by one on the building berth is shown in Fig. 10*a*. A further stage is shown in Fig. 10*b* with vertical framing and some of the bulkheads in position.

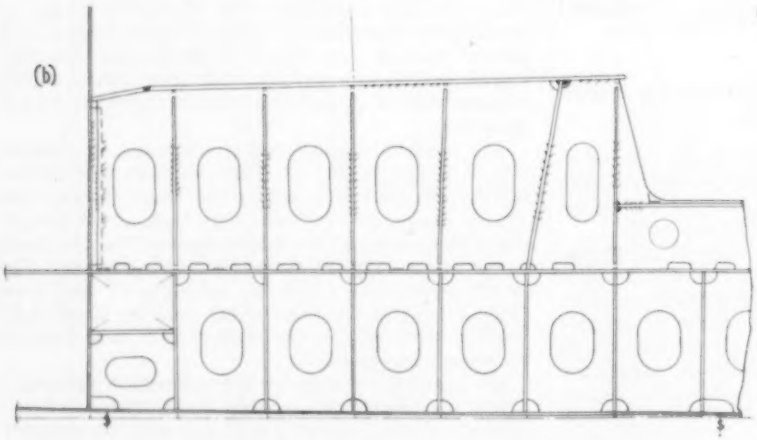
In contrast, Fig. 11 shows prefabricated welded units under construction in the welding shop, and Fig. 12 shows the engine-room bulkheads and fabricated after-unit as erected on the berth.

In much the same way, the construction of the modern all-welded high-pressure boiler, and the fabricated engine frame differs radically from their earlier riveted or cast designs.

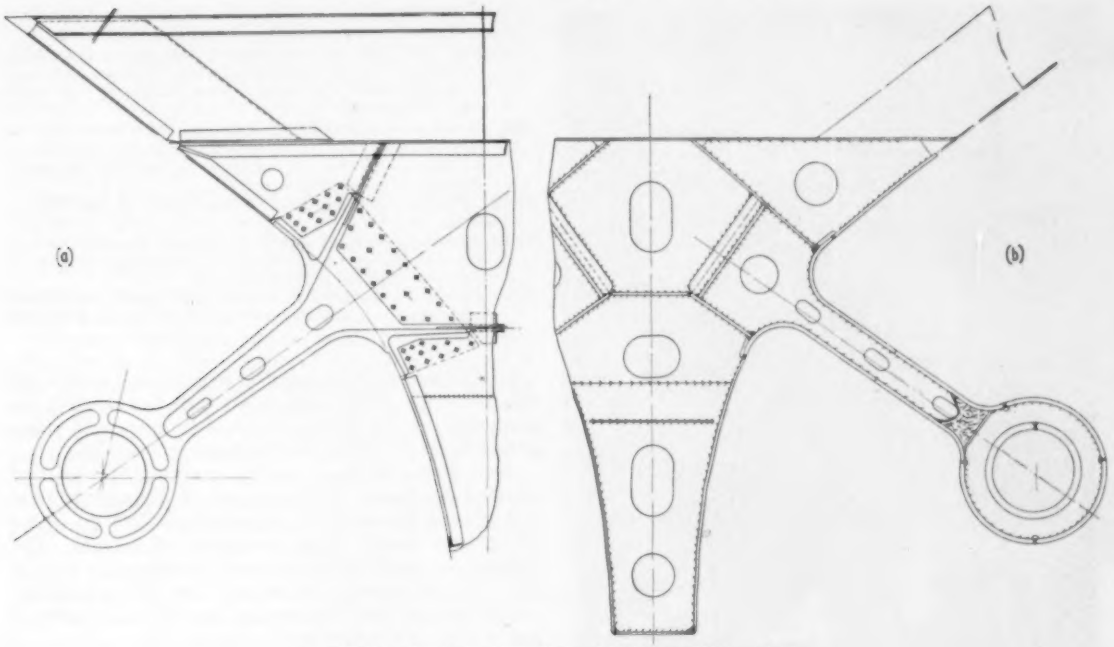


5—*Bottom framing for a large liner:* (a) *Riveted;* (b) *welded*

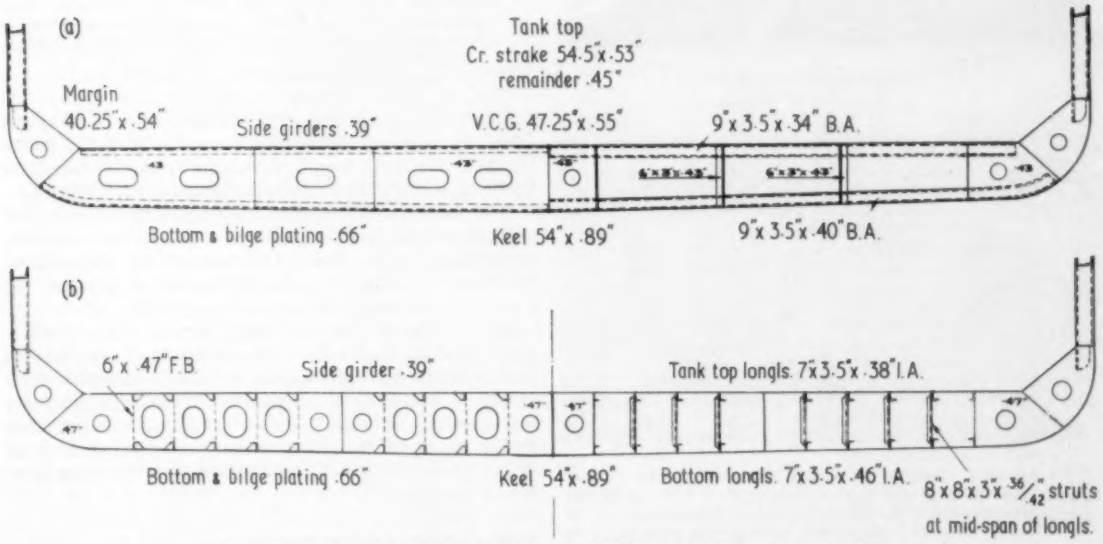




6—*Turbine seats for a large liner:* (a) *Riveted;* (b) *welded*



7—*Shaft bracket for a large liner:* (a) *Riveted;* (b) *welded*



8—*Sections through bottoms of cargo ships:* (a) *Riveted, with transverse framing;* (b) *welded, with longitudinal framing*

Brittle Failure

The measures taken to minimize the risk of brittle failure fall under three headings:

(*a*) Structural design
(*b*) Welding practice and inspection (both (*a*) and (*b*) to minimize the likelihood of a crack starting)
(*c*) Materials (to prevent or restrict propagation of a crack)

Structural design

I have referred to the need for unremitting attention at all stages of design to avoid notch effects or abrupt changes in section of the structural components so as to minimize stress concentrations. It would seem appropriate to list some of the detailed measures that are observed:

(i) Scantlings of longitudinal members are tapered gradually towards the ends of the ship without abrupt changes. Where plates are joined whose thicknesses differ by more than $\frac{1}{4}$ in., the thicker one is tapered down to the thinner plate
(ii) Longitudinal bulkheads and girders are continuous through transverse bulkheads

9—*Launch of H.M.S.* Contest

(iii) Longitudinal bulkheads in way of the vertical keel are well bracketed at their ends
(iv) The breakdown of stringer plates in the strength deck is separated from the breakdown of the sheer strake plating. The full strength of stringer plates is maintained in way of all openings in or adjacent to the stringer
(v) No holes or openings are cut in the sheer strake, which must not project above the weatherdeck. If it is riveted to a deck angle, the edge of the sheer strake is planed or ground before erection
(vi) The structure in way of the breakdown from forecastle to upper deck is designed to minimize the stress concentration in the sheer strake. The radius of the 'notch' in the sheer strake at the breakdown is not less than a specified minimum, and the use of high yield point steel in the sheer strake is recommended
(vii) Deck girders and beams are specified to be in alignment with bulkhead stiffeners
(viii) All deck openings have well rounded corners. Corner radii are not less than one-quarter of the transverse dimension or 6 in., whichever is less. Openings 12 in. or less in transverse dimension have corner radii equal to half the transverse dimension, except where an edge strip is fitted, when the radius may be reduced to more than 3 in.
(ix) In way of holes in plating, compensation in the form of a coaming is preferred to local doubling of the plating. Openings are arranged with the large dimension fore and after wherever possible
(x) If small holes (*e.g.* vent trunks) have to be positioned near large openings (*e.g.* funnel uptakes), they are worked as near the mid-length of the opening as possible
(xi) Plate edges after being cut to radius are ground smooth
(xii) Holes in beams or girders should not generally exceed one-third of the depth of the member. If this is exceeded, a reinforcing flange is fitted to the edge of the hole
(xiii) Holes in webs must not be cut in regions of high sheer. Holes in free flanges are not permitted
(xiv) Corners of long deckhouses or superstructures are rounded in plan where possible. Re-entrant corners are avoided
(xv) End bulkheads of superstructures are over a supporting bulkhead or deeper beam. Transverse bulkheads in superstructures are in the plane of main transverse bulkheads wherever possible
(xvi) Doors or other openings are clear of intersections of important superstructure bulkheads. Door openings on all adjacent decks are staggered to preserve the sheer strength of the superstructure
(xvii) Catwalks connecting deckhouses have one end free to slide
(xviii) Stressing of plate material through its thickness is avoided. If this is not possible, ultrasonic examination of the plate material may be required
(xix) Details are designed to ensure good access for welding and inspection, and to permit as much down-hand work as possible.

In addition to these practical measures, it is now the practice in the Admiralty to attempt to calculate the stress distributions in way of discontinuities, and hence to determine the sizes of reinforcements needed.

Even with the most careful structural design and working practices, some positions of stress concentration cannot be avoided, and small defects do occur which may result in the initiation of a crack. The precautions outlined minimize the likelihood of cracks, but it is considered prudent to take all practicable measures to prevent the propagation of a crack after it has started. There are two measures:

(*a*) The use of material, for the main longitudinal strength structure, that remains notch ductile under all operating conditions. We will further consider this measure in a later section of this lecture. It is the one adopted in current Admiralty practice.
(*b*) The use of 'crack arresters'.

Lloyd's Register requires the introduction of crack arresters in cargo ships, which can be provided either by the introduction of longitudinal riveted seams, or by the use of strakes of special notch-ductile plating.

It is understood that the U.S.A. Authorities specifically require the introduction of riveted seams in their commercial ships, and do not accept the alternative. This seems to indicate some divergence of opinion, but I am quite confident that Lloyd's are right.

Crack arresters undoubtedly can provide a safeguard against the spread of some forms of cracking. A riveted seam will stop a slow running non-brittle type of crack, but there is no guarantee that it will stop a fast running brittle crack. A strake of special non-brittle material would prevent the propagation of brittle failure, but would not stop slow running non-brittle cracks.

Welding practice and inspection

Careful design may largely eliminate undesirable stress raisers, but bad welding practices or incorrect welding sequences may lead to flaws or residual stresses (or both) which may contribute to crack initiation.

Although it is well known that successful pressure-vessel work calls for the strict application of developed welding techniques, it is not yet everywhere realized that the same requirement applies to work with the high-quality structural steels, and to work with mild steel thicker than $\frac{3}{4}$ in. This may impose limitations on the type and size of electrode, and on the cross-sectional areas of weld deposit, and call for control of the

heat flow conditions. The rates of flow of heat away from the welds can be critical, and must be under close control throughout the whole of the welding operation and during the subsequent cooling; and this may necessitate large-scale heating of the work. The procedures need to be determined on large-scale samples and equipment must be provided for their application on the full scale.

There is a parallel here with the welding of heavy structural fabrications, which are now used instead of heavy castings for stern frames and shaft brackets or indeed in the repair of heavy castings and forgings. It is general knowledge that this class of work calls for special techniques and precautions.

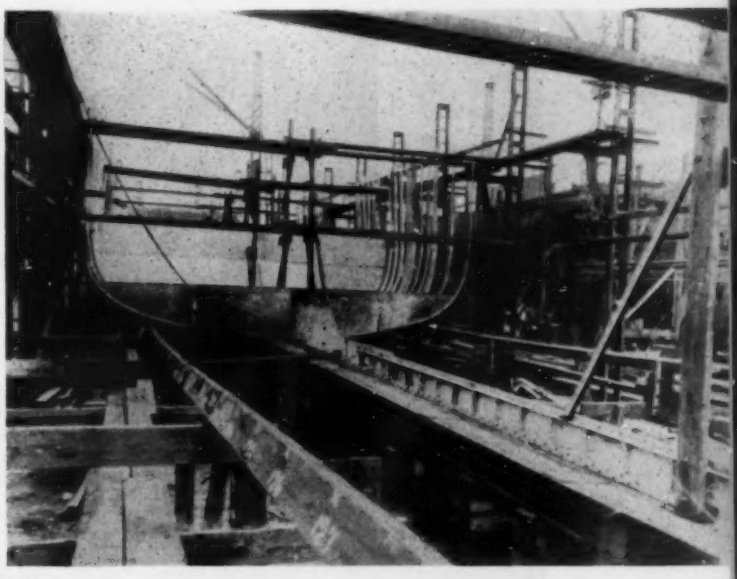
Stringent precautions are necessary to eliminate slag inclusions in multi-run welds. Fusion faces should be free of defects that might impair the weld quality. Hard spots resulting from stray arcing on otherwise intact plating are potential crack starters. The higher the quality of the steel the more important does it become to control casual and random welding work, such as temporary connections for assembly purposes and the attachment of small minor fittings. Even defective electric welding cables can cause serious damage by stray arcing. Any temporary attachments must be removed by chipping and grinding, and not by knocking off. Regulations for the proper care and storage of electrodes need to be laid down and enforced.

A welding sequence should be used to minimize distortion and locked-up stresses. Where possible, no welds should be made under restraints that tend to prevent shrinkage. In re-welding a cut-out portion, or an insert plate, preheat is recommended to reduce shrinkage stress. Emphasis is placed on careful assembly of items to be joined by welding, and bad edge preparation must not be tolerated.

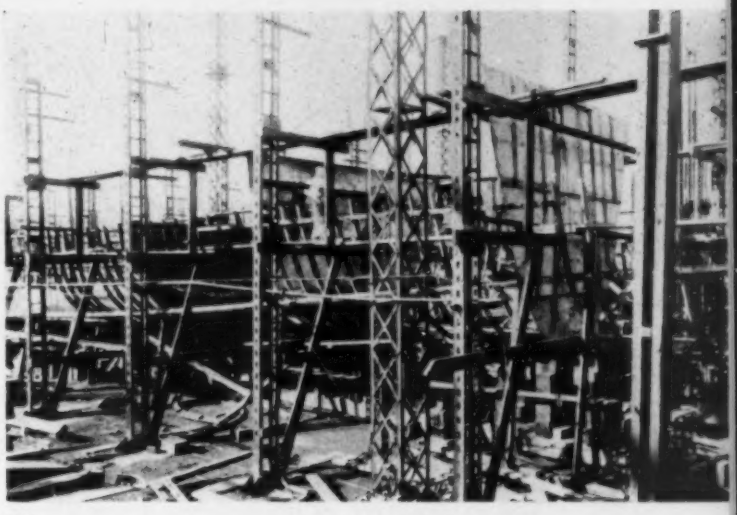
A thorough check on the quality of welding should be kept by visual and radiographic inspection.

Distortion is very troublesome with light plating, particularly on superstructure work, and to obtain a good fair appearance there is justification for the use of riveting.

There is also a need to prepare specifications for and to organize a proper control of any welding repair work in yards throughout the world. Perhaps not so vital for mild steel structures, it becomes of great importance for ships in which high-quality steels are used; *e.g.* should it become necessary to cut a temporary opening in the main structure of a welded ship, the subsequent welded insert plate repair needs to be carried out to the same precise procedure followed in the building yards.



(a)



(b)

10—*Building of riveted destroyer hull:* (a) *Keel with transverse frames erected one by one;* (b) *riveted framing and bulkheads erected on berth*

Non-destructive inspection

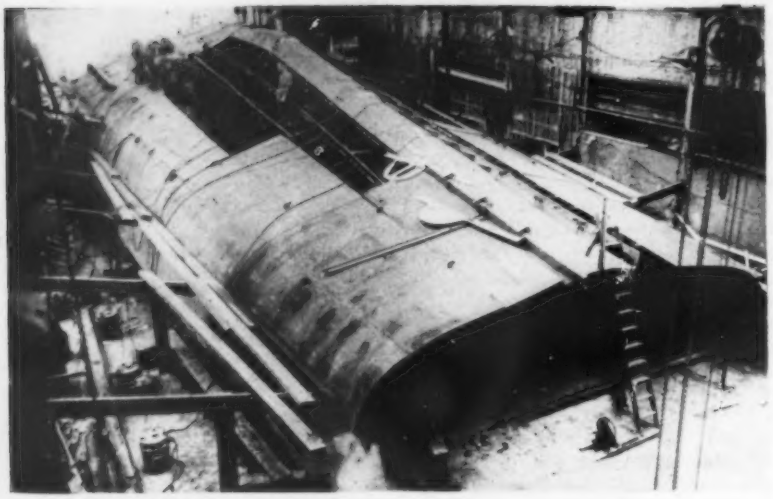
To meet the requirements for a high standard of welding workmanship, modern non-destructive methods of inspection have been developed. The Admiralty have found them invaluable as a means of controlling the quality of production work, as well as in the development of optimum welding procedures and in the training of welders to appreciate the need for adherence to the specified welding techniques.

Four methods are now in common use:

(i) Magnetic crack detection
(ii) Dye penetrants
(iii) Radiography
(iv) Ultrasonics.

The first two methods in shipbuilding are essentially aids to visual inspection. Portable equipment is necessary and, with limited power available, it is used for the detection of flaws reaching the surface of the material. Magnetic crack detection has recently been used to examine hot partially completed welds on important items in thick material. The preheat has been maintained during the inspection, and any defects are dealt with as the weld is being made. This procedure can effect economy in repairing weld defects.

(a)



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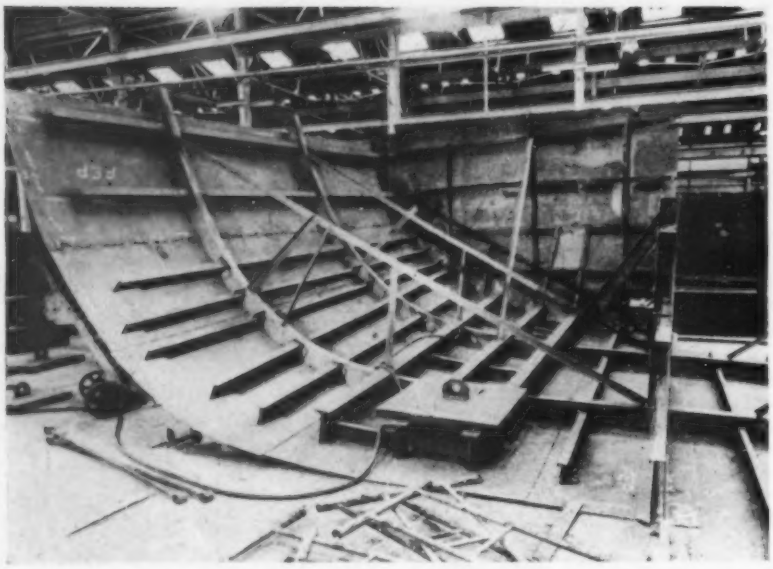


11—*Prefabricated units of destroyer hull:* (a) *After shell unit;* (b) *portion of side plating*

Radiography is used for the examination of completed welds, and where the material thickness exceeds ¾ in. radiography and ultrasonic detection are used as complementary methods.

Broadly, radiography is used to detect gas and slag inclusions, and transverse and crater cracks, whilst ultrasonics serve to detect longitudinal cracks and lack of fusion in the weld and fusion zones. Radiography has a low sensitivity in the detection of flaws in planes at an angle to the direction of the X-ray or gamma-ray beam.

The main advantages of ultrasonic inspection as compared with radiography are:

(*a*) There is no health hazard
(*b*) Other work in the vicinity of the inspection is not interrupted
(*c*) Ultrasonic inspection is approximately five times as fast as radiography on site, so that inspection costs are reduced
(*d*) Welds unsuitable for radiography can frequently be examined ultrasonically; *e.g.* full fusion tee butt welds, which are of particular importance in highly stressed parts of engine frame structures.

To overcome the disadvantage of the lack of permanent records, ultrasonic inspection is carried out by a small team of highly trained operators using proven techniques. Work of major importance, such as pressure hulls of submarines, is subjected to 100% inspection by ultrasonics and with not less than 10% check testing by radiography. The welded joints of thick walled pressure vessels (up to 6 in.) are subjected to 100% inspection by both radiographic and ultrasonic methods.

For structural welds on surface ships, non-destructive testing is applied to selected sample welds in the main structural material. We pay attention to positions where high stress is expected and where the execution of the work may be awkward.

These forms of testing are considered to be an essential requirement for the quality control of welded work. They are already widely used, but it is hoped that it may soon become a compulsory form of examination for all major structural welding in all ships.

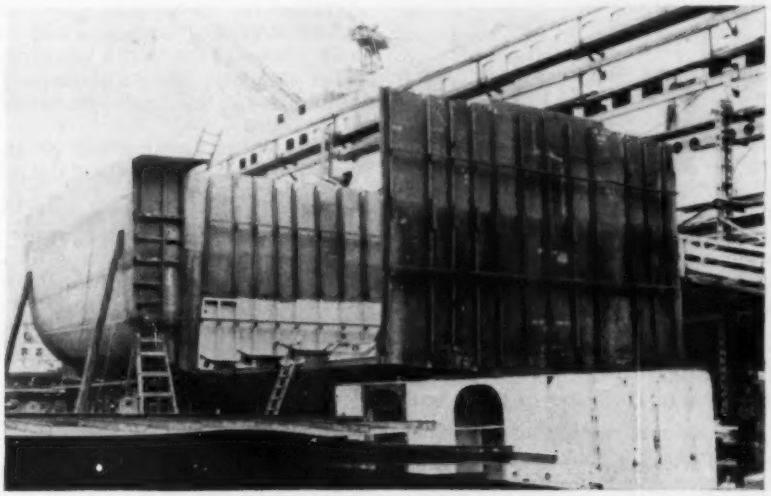
Structural material

The requirements for shipbuilding have played a leading role in the developments of steel, and the Admiralty has always been in the forefront of the work. Experience with the brittle-type fractures in ships led to a great deal of research both in Britain and in the U.S.A., the closest liaison being maintained between the British and American Committees set up to deal with the problem.

Higher yield point steels have also been developed, and a steel with a yield point of about 30 tons/sq.in. is being used. The high yield point steels are normalized and tempered, or quenched and tempered, and their welding presents an up-to-date challenge which the warship builder is facing.

A point of primary importance arises from this discussion. It is not sufficient just to develop welding techniques to cope with available steels, or to restrict steel compositions so as to make them more easily welded with existing welding techniques.

The progress we have so far made has been achieved by advances with welding techniques at the same time as improvements have been realized in steel making. What we mean by weldable steel is not the same now as it was 10 years ago. After experiencing welding troubles with structural high-tensile steel, welding research and development underlined the important influence of alloy content on the weldability of steel. This led to a realization that improvements in strength of structural steels could best be achieved by improved heat-treatment, since the weldability requirement set a limit on the amount of alloy in the composition. Simultaneously, research into the mechanism of weld and heat-affected-zone cracking indicated the importance of low-hydrogen electrodes and methods for controlling the cooling rate, such as preheating. These developments extended the range of weldable steel compositions and thicknesses.



12—Engine room bulkheads and fabricated after unit erected on berth

Resulting from the post-war research work, Lloyd's Register of Shipping has supplemented its Rules concerning the quality, testing, and approval of materials. The American Bureau of Shipping has also introduced safeguards into its requirements for ship steel.

In the 25th Andrew Laing Lecture, Sir Victor Shepheard[11] discussed the development of the structural steels used by the Admiralty for warship building, together with the problems of avoiding brittle fracture and of welding under shipyard conditions.

The Admiralty work has led to the adoption of two types of steel for warship work. Each has the requisite strength and ductility together with adequate notch toughness and good weldability.

One, specified as Type A, is a notch-tough mild steel for thicknesses of $\frac{1}{2}$ in. and over, with a specified yield point of 16 tons/sq.in. up to 1 in. thickness, and 15 tons/sq.in. for greater thicknesses. The other, Type B, is a structural steel with a yield point of 20 to 18 tons/sq.in. according to thickness. Both steels are subject to a Charpy test of 30 ft.lb at $-30°C$, with fractures showing not more than 75% crystallinity. Extensive research has shown that these steels are able to prevent cracks propagating even under conditions of low temperature or high rates of loading.

Hence, we have been led to improved notch-tough steels for high yield strength and, at the same time, to changes in shipyard techniques including greater care of electrodes and the installation of special preheat arrangements on a large scale. To supply quenched and tempered plates in shipyard sizes, the steelmakers have had to install special quenching plant.

The new steels are expensive, but the cost can be partly offset if the design uses the modern steels efficiently, taking advantage of their yield strengths of about 20–25% above those appropriate to the earlier steels. Account must be taken of the fact that the

fully-killed notch-tough steels are, with present steel-making practice, bound to be 'dirtier' than the older mild steels. This is important from a welding viewpoint, especially where a good deal of fillet welding is unavoidable. It is, therefore, necessary for plates to be checked ultrasonically if they are required to have good strength through-the-thickness.

Aluminium alloys

The aluminium alloys are coming into wide use for superstructures and internal work, and they call for yet more detailed welding design. The material lends itself to the extrusion of sections in great variety, which can be designed to facilitate economical welding details arranged both to avoid undue conglomeration of the welds and to make them convenient of access to the welders.

Has Welding affected Ship Corrosion?

Corrosion is perhaps the major problem in ship maintenance. Does welding affect it? I understand that both Lloyd's and the Admiralty agree that no new major or general corrosion trouble has been introduced by welding, and that welded deposits do not show any special tendency for more corrosion than is general to the structure as a whole.

However, corrosion of plating and preferential corrosion of welds can be associated with the presence of mill scale on the plates. It is, of course, important that hull plating should be cleared of mill scale either by pickling or shot blasting.

Other possible causes of corrosion of steel weldments are:

(*a*) Improperly removed welding slag
(*b*) Inadequate, poorly adherent or blistered paint films
(*c*) Roughly finished weld, causing paint to be removed by abrasion or erosion
(*d*) Entrapped hydrogen, which lifts the paint film if it has been applied too quickly after welding.

The British Shipbuilding and Research Association is at present collecting information on the extent of weldment corrosion, and the Admiralty is collaborating.

Instances of appreciable hull corrosion of H.M. ships during the 'fitting-out' afloat stage have been attributed to earth return currents from shore supply d.c. welding sets. This can, of course, be avoided by operating the shore generator in an earth-free condition, the only earth connection being that made to the ship's hull. If it should be essential to employ a single generator for simultaneous d.c. welding in two ships, the shore generator should be earth-free, and the two ships' hulls connected together by low-resistance cables.

The changeover to a.c. welding systems by many shipyards is removing the risk of this type of corrosion.

Galvanizing

For the light, fast types of small riveted warships, galvanizing of the plating made an important contribution to the preservation of the structure. Unfortunately, galvanized material is not suitable for welding. Grit blasting followed by metallization is a not so good alternative, which also suffers from disadvantages of its own.

The Future

I have referred to advances already made and I think we can be proud of them. But the challenge for still better design using still better materials persists, emphasized by the application of nuclear power. We need to use higher strength materials, and their welding problems are unlikely to become any easier.

Perhaps the most urgent immediate need is for an automatic welding equipment that could be used even in the congested spaces of a submarine.

The long-term process of educating all sections of the shipyards—from management downwards—must be continued.

Collaborative research will go on and the Naval Architects and Engineers will do their best to apply the results.

Acknowledgments

The paper is presented with the permission of the Admiralty, and the author is indebted to the Director General Ships for leave to read it. He would also like to acknowledge the valuable help and encouragement given by colleagues of the Admiralty, Lloyd's Register of Shipping, the Shipbuilding Industry, and the permission from Lloyd's, Messrs. Vickers-Armstrongs and Messrs. J. S. White to use some of their drawings.

However, the responsibility for statements of fact or expression of opinion rests solely with the author.

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Welding
RESEARCH

B.W.R.A. REPORT

Autogenous Argonarc Welding of Zinc-Deoxidized Copper

By K. J. Clews, A.M.INST.W.

It has been shown that 18 s.w.g. copper containing up to 3% of zinc is weldable by the argon- or helium-shielded tungsten-arc process without the use of filler metal. Weld strength in annealed sheet, with a flanged edge close-butt weld preparation was, in the most adverse case, at least 300 lb per inch of seam, or with full penetration, at least 1500 lb/in.

Variations in zinc content had no detectable effect on the strength of fully penetrated welds. The current required for full penetration welding was more closely related to welding speed and gas flow rate than to thermal conductivity of the sheet, which decreases with increasing zinc content.

Whilst argon and helium were both suitable as shielding gases, argon is to be preferred for economy and ease of arc starting. Nitrogen gave rise to gross porosity and is unsuitable for this material.

The corrosion resistance of welded specimens was investigated by immersion in boiling hydrochloric acid. None of the alloys were susceptible to dezincification of crevice attack.

Cap copper containing 3% of zinc is recommended as a substitute for phosphorus-deoxidized copper. Where higher conductivity is desirable, an alloy containing less zinc is suggested.

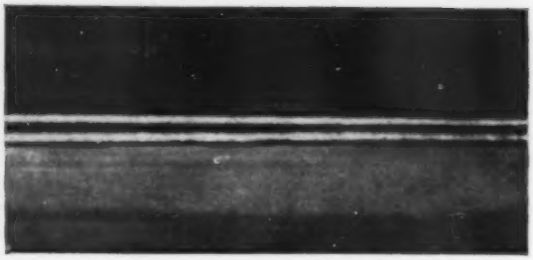
SOME 6000 tons of light-gauge copper, usually deoxidized with phosphorus, are used annually in the manufacture of domestic water cylinders and tanks. It is customary to torch braze these articles with an expensive copper-silver-phosphorus alloy filler, and the brazing time for a typical tank is of the order of 15 min. Many manufacturers have expressed interest in the replacement of brazing methods by welding, knowing that welding is quicker and need not involve the use of filler metal. Unfortunately, phosphorus-deoxidized copper is unsuitable for welding without the addition of a filler, since there is insufficient deoxidant present to combat adventitious oxygen and water vapour in the arc atmosphere. A typical autogenous weld in phosphorous-deoxidized copper is illustrated in Fig. 1. The use of filler metal with light-gauge sheet is undesirable, since it introduces difficulties in feeding and setting up, and welds tend to be uneven in shape and variable in quality.

Clearly, it was necessary to replace phosphorus-deoxidized copper by an alloy containing a deoxidant in sufficient quantity to deal with oxidizing gases in the arc, and having a minimum effect on electrical and thermal conductivity. It was considered preferable that such an alloy should be available commercially, and should have mechanical properties similar to phosphorus-deoxidized copper, so that manufacturing and forming costs would be comparable. The corrosion

Report C3/4/59 of the British Welding Research Association, issued to members in January 1960.

Mr. Clews is a Senior Experimental Officer of the British Welding Research Association.

1—*Flanged butt weld in phosphorus deoxidized copper*



2—*Flanged butt weld in Cu–3% Zn alloy*

resistance of the alloy would need to be high, since some supply waters are aggressive. Dilute copper-zinc alloys appeared to answer these requirements, the alloy containing 3% of zinc being commercially available under the name "cap copper".

Materials

Suitable quantities of cap copper containing 3% Zn and electrolytically refined copper were melted in plumbago crucibles under a cover of Cuprit 49* to produce the alloys of composition detailed in Table I.

Table I
Composition of zinc-deoxidized coppers

Alloy	*Cu, %*	*Zn, %*	*P, %*
1	99·90	0·09	<0·0005
2	99·71	0·28	,,
3	99·12	0·87	,,
4	98·57	1·42	,,
5	97·01	2·98	,,

Charges were super-heated to 1140°C. and were poured into iron cake moulds which had been preheated to 900°C. The ingots were planed to remove surface defects, and were strip rolled to a finishing thickness of 0·048 in. before being annealed in a reducing atmosphere.

Experimental

It was difficult to produce satisfactory unfilled close-butt square-edge welds in 18 s.w.g. sheet because of the need for extreme care in setting up and close control of welding conditions. Small variations from the optimum resulted in incomplete penetration or burn-through. Moreover, the best welds had no reinforcement, the upper surface being sunk below the level of the sheet.

It was considered that a flanged close-butt weld preparation was to be preferred to the unfilled close-butt type; a weld is illustrated in Fig. 2 which had the edge preparation depicted in Fig. 3*a*, and which was adopted for the remaining butt welds. Strips measuring 6×3 in. were cut from each alloy, and a long edge on each strip was flanged, abraded with fine wire wool, and degreased with petroleum ether before being placed in a jig (Fig. 3*a*). Corner welds were made with the two types of preparation shown in Figs. 3*b* and 3*c*.

* Supplied by Foundry Services Ltd.

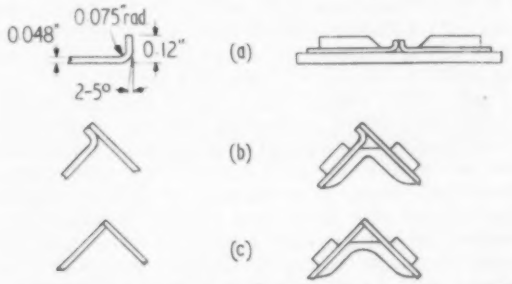
The method of jigging for corner welding is also shown in Fig. 3, and typical joints are illustrated in Figs. 4–6.

Butt and corner welds were made automatically by the d.c., electrode-negative, tungsten-arc process with either argon or mineral helium shielding gas. A few melt runs were also made on all the alloys under argon, oxygen-free nitrogen, and mineral or atmospheric helium, so as to investigate the effect of covering gas on the incidence of porosity. All welds and melt runs were radiographed (Fig. 7), and the zinc loss due to welding was determined by chemical analysis.

Conditions for butt welding are set out in Table II, which also records the breaking load per inch of weld, the values being obtained from tensile tests on two pieces cut from each weld. This table also includes an indication of the position at which fracture took place, and an estimate of the ultimate tensile strength of the welds based on the cross-sectional area of the strip. Excellent welds were produced at 36 and 60 in./min travel speed, and fit-up was not critical even at the higher speed. As an example of suitable welding conditions, a current of 230 amp with an argon flow of 12 cu.ft/hr and travel speed 36 in./min may be cited. Manual welding was equally effective.

Shielding of a corner weld in the downhand position required a greatly increased gas flow compared with a butt weld at equal travel speed; consequently, to reduce gas consumption, the welding speed was reduced to 12 in./min during downhand corner welding. The welding conditions are recorded in Table III.

Accelerated corrosion tests were conducted on pieces of each butt weld by immersing duplicate specimens from each alloy in a 1000 ml flask containing 500 ml of 65% HCl by volume. The acid was boiled continuously under reflux for one week; the specimens

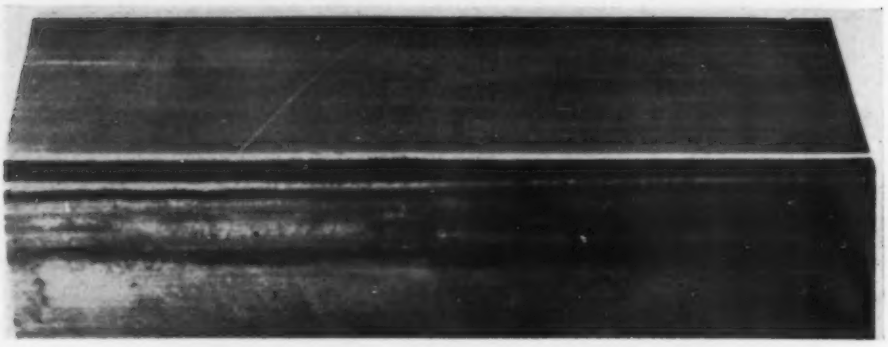


3—*Edge preparations and jigging methods*: (a) *Butt welds;* (b) *corner weld, type I;* (c) *corner weld, type II*

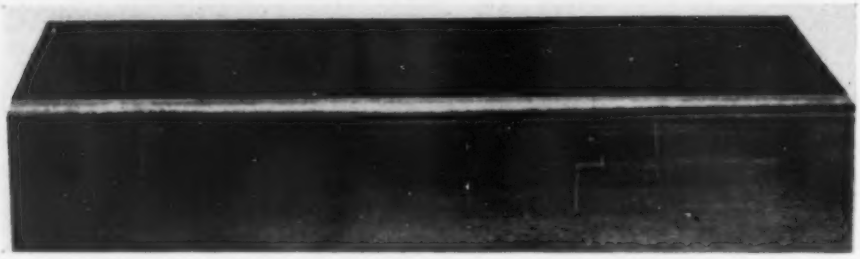
Table II
Welding conditions and strength of butt welds

Zinc %	Helium												Argon												Zinc %
	20 cu.ft/hr						42 cu.ft/hr						12 cu.ft/hr						20 cu.ft/hr						
	36 in./min			60 in./min			36 in./min			60 in./min			36 in./min			60 in./min			36 in./min			60 in./min			
	Current, amp	Strength lb/in.	Strength tons/sq.in.	Current, amp	Strength lb/in.	Strength tons/sq.in.	Current, amp	Strength lb/in.	Strength tons/sq.in.	Current, amp	Strength lb/in.	Strength tons/sq.in.	Current, amp	Strength lb/in.	Strength tons/sq.in.	Current, amp	Strength lb/in.	Strength tons/sq.in.	Current, amp	Strength lb/in.	Strength tons/sq.in.	Current, amp	Strength lb/in.	Strength tons/sq.in.	
0·09				250	1915 1890	16·7 S 16·7 S	160	1870 1960	17·1 S 17·2 S	240	1980 1870	17·6 S 17·0 S	210	1228 1210	10·8 W 10·8 W	310	1935 1850	17·3 S 16·6 S	235	1845 1860	17·2 S 16·7 S	290	1650 1770	14·1 H 15·3 W	0·09
							190	1900 1830	16·9 S 16·8 S				230	1525 1890	13·6 W 16·5 W				270	1985 2008	18·1 S 18·5 S				
0·28	160	1600 1685	14·7 W 15·3 W				150	1275 1493	11·2 W 12·7 W							230	650 625	5·8 W 5·8 W	190	1430 1680	12·5 S 15·0 W				0·28
	190	1438 1465	12·8 W 12·8 W				160	1825 1830	16·3 H 16·3 H							235 245	1020 725 1265	9·6 W 8·3 W 10·9 S							
0·87	165	1855 1845	16·3 S 15·8 S	220	1462 1850	12·3 W 16·2 S	160	1380 1560	12·2 W 13·4 H	200	1718 1860	15·1 W 16·4 S	250	662 334	5·6 W 2·9 W	280	1260 1400	11·0 H 12·1 W	240	1780 1500	15·6 S 12·7 W	290	1292 1550	11·4 H 13·1 H	0·87
																			250	1480 1640	13·0 H 14·5 H	295	1182 1378	10·4 H 12·1 W	
1·42	165	1520 1472	13·0 H 12·8 H	220	1970 1860	17·3 S 16·6 S	160	1883 1850	15·9 S 16·2 S	220	1880 1910	16·4 S 16·7 S	250	1865 1760	15·9 H 15·5 H	320	1865	16·1 S	265	1215 1625	10·4 W 14·0 H	300	1845 1915	15·9 H 16·8 S	1·42
																						325	2001 2000	17·6 S 17·0 S	
2·98	140	1221 1008	10·8 W 8·5 W	100	368 383	3·0 W 3·2 W	150	1890 1945	17·3 S 18·2 S	100	376 400	3·2 W 3·4 W	170	532 500	4·7 W 4·5 W	170	849 849	4·8 W 4·8 W	170	510 508	4·8 W 4·5 W	260	1258 1210	11·3 H 11·1 H	
	150	1300 1385	11·4 W 12·4 W	130	531 551	4·6 W 4·7 W				180	1485 1455	13·4 S 12·8 S	200	1544 938	13·8 H 8·2 W	200	632 649	5·6 W 5·7 W	200	1162 1162	10·0 W 10·0 W	280	1022 1120	9·2 W 10·0 W	2·98
	160	1638 1675	14·1 S 14·8 S	160 190	955 961 1618 1618	9·2 W 9·2 W 14·5 S 14·5 S							230	1518 1525	13·7 H 13·8 W	230 245	720 638 1356 1265	6·3 W 5·6 W 12·1 H 12·6 H	230 250	1462 1598 1630 1658	13·0 H 14·2 S 14·5 S 14·9 S	315	1468	12·9 S	

W indicates that fracture occurred through the weld
H indicates that fracture occurred in the heat-affected zone
S indicates that fracture occurred in the sheet



4—*Flanged corner weld (type I of Fig. 3)*



5—*Edge-to-edge corner weld (type II of Fig. 3)*

Table III

Optimum conditions for corner welds in argon

Weld Type (Fig. 3)	*Current, amp*	*Arc Voltage, V*	*Gas Flow, cu.ft/hr*	*Travel Speed, in./min*
Type I	140	17	20	12
Type II	135	14	20	12

were then removed, sectioned, and examined metallographically for evidence of dezincification and other forms of corrosive attack.

Results

Effect of composition

Table II indicates that there is no significant increase in weld strength with increase in zinc content. The current required to produce welds of similar shape was the same for all alloys, other things being equal, so that differences in thermal conductivity between the alloys examined are not of importance during welding.

The amount of fume given off during welding increased as the zinc content increased, but even with 3% Zn it was not objectionable. In this alloy the weld metal contained 0·1% less zinc than the sheet, whilst in the more dilute alloys the loss amounted to no more than 0·02% Zn.

With argon or helium shielding, porosity was low in both the low- and high-zinc alloy welds, being most severe in the alloys containing 0·3–0·9% Zn (*see* Table IV).

Table IV

Porosity in butt welds

Zn, %	*Number of Welds with Stated Level of Porosity in: Helium*		*Argon*	
	Low	*High*	*Low*	*High*
0·09	4	0	4	2
0·28	0	4	1	7
0·87	2	2	0	6
1·42	4	0	5	0
2·98	7	1	8	4

Effect of shielding gas

Helium—The ionization potential of helium is high, so that power sources with high open-circuit voltages are necessary to avoid arc starting difficulties.

Radiographs of melt runs clearly showed that mineral or atmospheric helium was better than argon in preventing porosity (Fig. 7). Differences between the two gases were less pronounced in welds, probably because, with melt runs, air beneath the sheet is unlikely to exert a great influence, whereas, in welds, there is restricted access of air from beneath the sheet to the weld pool.

Argon—Power sources with low open-circuit voltages can be used, and although porosity was higher in argon than in helium, the weld strength was not affected. It is clearly economical to use argon because it is cheaper than helium and because weld coverage is better than with helium at equal flow rates.

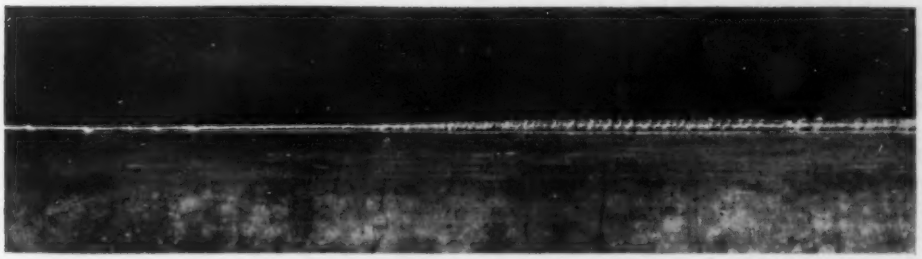
Nitrogen—Melt runs shielded with oxygen-free nitrogen were grossly porous (Fig. 7). The gas is considered to be unsuitable for the Cu–Zn alloys.

Effect of porosity with argon and helium shielding

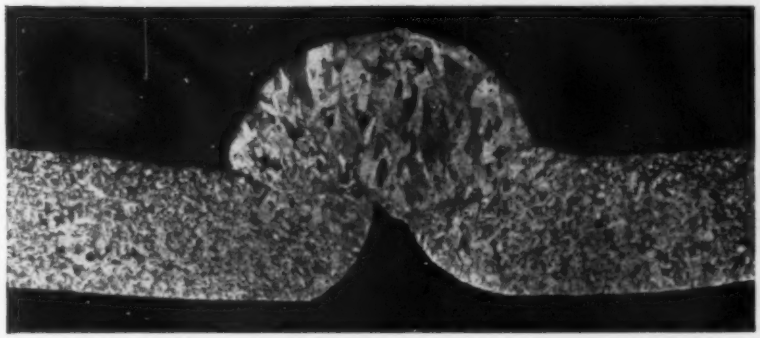
Weld strength was unaffected by the presence of porosity. Duplicate test pieces, cut from the welds at random, almost invariably had different degrees of porosity; despite this, breaking loads were similar.

Effect of weld shape

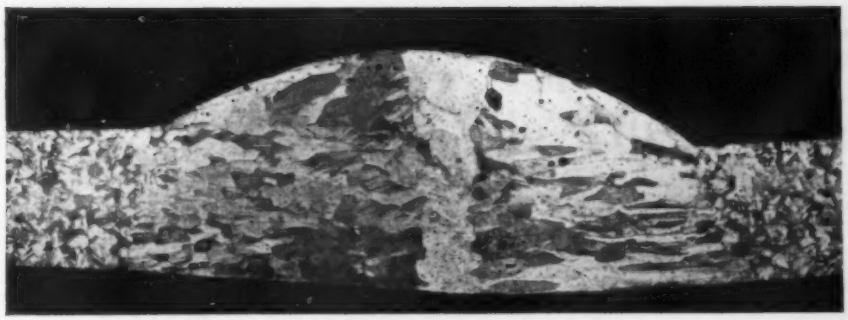
Weld shape was determined by current, welding speed, and gas flow. The variations obtained are shown



6—*Underbead of weld illustrated in Fig. 5*



(a)

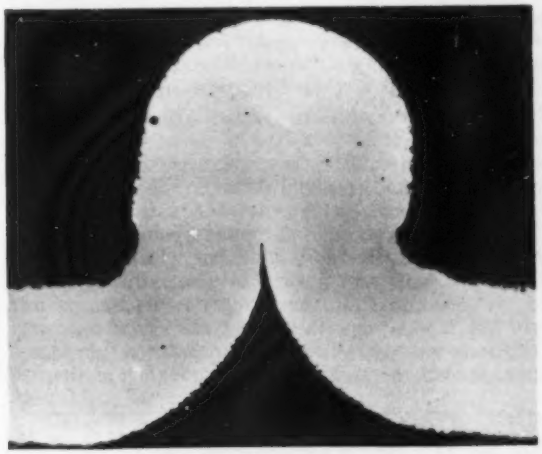


8—*Weld shapes:* (a) *Minimum penetration;* (*b*) *full penetration* (b)

A—Shielded with argon
H—Shielded with helium
N—Shielded with nitrogen

A H N

7—*Radiograph of melt runs on Cu–3% Zn alloy*



9—*Weld after corrosion testing*

in Figs. 8*a* and 8*b*. Even with minimum penetration, weld strength was at least 300 lb per inch run of weld, fracture taking place through the weld. In fully penetrated welds, such as that shown in Fig. 8*b*, strength was at least 1500 lb/in., with fracture in the sheet.

Corrosion tests

There was no evidence of dezincification even in the

alloy containing 3% Zn. Corrosive attack was slight and was intergranular in character, with the appearance illustrated in Fig. 9. This shows that sheet and weld metal corrode at equal rates under these conditions, so that premature failure by localized attack is unlikely. There was no evidence of susceptibility to crevice corrosion.

Conclusions

The following conclusions have been drawn from this investigation:

(1) Zinz-deoxidized coppers containing up to 3% Zn can be welded without encountering serious porosity, using either the argon-tungsten-arc or helium-tungsten-arc processes. Argon is preferred for economic reasons. Nitrogen is unsuitable as a shielding gas.
(2) The zinc content is relatively unimportant, the only noticeable effect being a slight increase in fuming as the content increased. Zinc losses are insufficient to lead to corrosion difficulties.
(3) Welding conditions for flanged edge close butts, edge welds and flanged corner welds are not critical. Edge-to-edge corner welds are difficult to make. Butt weld properties in 18 s.w.g. sheet are good, and vary from 300 lb/in. withs light penetration, to 1500 lb/in. with full penetration.
(4) The risk of dezincification or crevice corrosion is negligible in the alloys examined.

Since the mechanical properties and formability of zinc-deoxidized copper containing up to 3% Zn are similar to those of phosphorus-deoxidized copper, and since zinc has the least effect of all the common alloying elements on electrical and thermal conductivity, these materials are suggested as adequate substitutes for phosphorus-deoxidized copper. In some circumstances the high-conductivity low-zinc alloys may replace tough pitch copper for welding applications, but in such cases the phosphorus level must be kept low.

The use of zinc-deoxidized copper will enable water tanks and cylinders to be autogenously welded. Material containing 3% Zn is sold commercially under the name "cap copper".

Generalized Theory of Super-Solidus Cracking in Welds (and Castings)

AN INITIAL DEVELOPMENT

By J. C. Borland, A.I.M.

The tendency for super-solidus cracking in welds depends on the quantity and distribution of liquid around grain boundaries during freezing through a critical solidification range. The liquid distribution is largely determined by the ratio of interphase (solid-liquid) and grain-boundary energies. Low ratios (slightly greater than 0·50) existing over a relatively wide temperature range are harmful because almost continuous *films cover grain faces and thus allow high stresses to be built up on the narrow bridges joining dendrites. High ratios (above 0·57) are beneficial because then the liquid is restricted to grain edges and corners.*

VARIOUS attempts have been made to explain super-solidus cracking in welds, but as yet no completely acceptable thesis has been developed. Some workers argue that the basic cause of cracking is the inability of the semi-rigid network of interlocked dendrites to withstand the shrinkage strains imposed upon it during cooling through a 'brittle temperature range'. Others believe that cracks are formed during the last moments of solidification when a liquid film stage is reached. Experimental evidence is available that supports both these theories.

The generalized theory, presented here, attempts to reconcile, modify, and extend these two theories, and to explain how the liquid quantity and distribution during freezing affects the cracking tendency. In particular, it is suggested that the distribution of liquid is largely influenced by the ratio of the interphase (solid-liquid) and intercrystalline boundary energies. A low ratio tends to develop liquid films which cover both the grain faces and the edges, whereas a high ratio tends to confine the remaining liquid to edges and corners. The latter arrangement is beneficial because relatively large areas of the grain faces can unite and thus enable the weld to accommodate the thermal

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Mr. Borland is with the British Welding Research Association.

stresses created during cooling. This prevents fissures being formed.

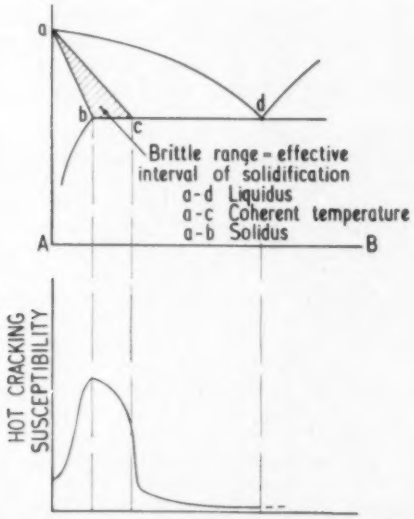
The theory is equally applicable to castings.

Previous Theories

Shrinkage-brittleness theory

The origins of this theory[1–7] undoubtedly result from numerous studies of hot-cracking (tearing) tendencies of aluminium alloys, but the ideas developed are equally applicable to other alloys systems.

The mechanism of cracking is thought to be as follows. At some time during the liquid-solid stage, the primary dendrites, growing at the expense of the decreasing volume of liquid, come into contact for the first time (coherent temperature) and interlock, thereby forming a coherent network. During subsequent cooling, contraction strains develop, and when the critical rupture stress has been exceeded a rift will occur in the network. These newly formed fissures will then persist if there is insufficient liquid remaining to 'heal' them. Once the alloy has passed safely below the solidus, cracks are unlikely to form, it being assumed that the solid metal is ductile at these temperatures. Cracking therefore is only likely to occur in the 'brittle range'[6] (=effective interval of crystallization[3]) *i.e.*, the range of temperature between the coherent temperature and solidus (see Fig. 1).



1—*Hot cracking susceptibility of eutectiferous alloy. (Shrinkage brittleness theory)*

'Accommodation'[6] is the degree to which an alloy is able to withstand shrinkage strains by movement of the crystals within the semi-solid mass. It acts to prevent cracking when the alloy is cooling through the 'brittle range'. According to Pumphrey and Jennings[6] the cracking tendency is proportional to the extent of the 'brittle range'.

These various ideas have been extended by Medovar,[8] who states that the variation of hot cracking with alloy additions, for elements forming continuous solid solutions, is determined by the length of freezing range. If elements are not mutually soluble in either the liquid or solid state, then hot cracking should not occur. For systems that do not form primary solid solutions, even very small additions of the second element will cause severe cracking, owing to the rapid increase in the freezing range, whilst further additions should tend to reduce cracking.

In general, if the freezing range is very short, hot cracking should not occur.

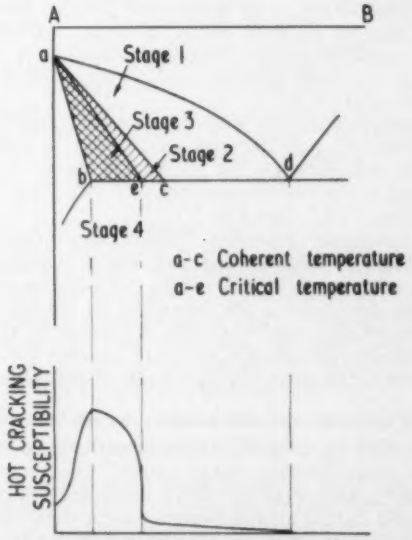
Strain theory of hot tearing

Pellini[9] and his co-workers,[10–12] the originators of this theory, suggest that hot cracking is caused by the localized strains, set up by the thermal gradients, tending to pull apart solid masses of material separated by *essentially continuous** thin films of liquid. In slight contrast to the previous theory of cracking, it is argued that hot tearing cannot occur during the mushy stage of solidification, since the shrinkage strains are uniformly distributed. Cracking takes place only when the film stage is reached and the localized strains are exceedingly high. Low-melting point segregates which exist, in the molten state, below the equilibrium solidus of the material, are the most dangerous in this respect.

Generalized Theory

Obviously, welds are susceptible to cracking between the coherent temperature and the solidus. There are, however, various ways in which the dendrites can unite and restrict the flow of the remaining liquid.

* It is not clear whether the authors meant "continuous" or "almost continuous".



Stage 1—Dendrites freely dispersed in liquid. No cracking
Stage 2—Interlocking of grains. 'Liquid healing' possible if cracks form. 'Accommodation' not important
Stage 3—Critical solidification range. No 'healing' of cracks possible if 'accommodation' strain exceeded
Stage 4—Solidification. No cracking
a-e-e—Brittle range

2—*Effect of constitutional features on cracking susceptibility in binary systems. (Generalized theory)*

Furthermore, the mode of the co-existence of the liquid and solid changes in cooling, and so it is to be expected that different interlocked crystal formations will affect the cracking tendency differently. Thus the events taking place during the cooling from liquidus to solidus require careful consideration.

Effect of freezing mode

The freezing process may be pictured thus (see ref. 13):

Stage 1 (Primary dendrite formation)—The solid phase is dispersed while the liquid is continuous; both liquid and solid phases are capable of relative movement.

Stage 2 (Dendrite interlocking)—Both liquid and solid phases are continuous, but only the liquid is capable of relative movement and is able to circulate freely between the interlocking dentrites.

Stage 3 (Grain boundary development)—The solid crystals are in an advanced stage of development and the semi-continuous network restricts the free passage of liquid. Relative movement of the two phases is impossible.

Stage 4 (Solidification)—The remaining liquid has solidified.

In agreement with other workers, the present author believes that materials are susceptible to cracking once they have cooled below the coherent temperature; this is solidification stage 2 in the freezing process outlined. Further, if a crack is initiated at this stage, it is possible for 'healing' to occur by a flow of liquid into the void so formed, particularly when there is a high proportion of liquid present.

Previously the relative importance of 'healing' and 'accommodation' has not been sufficiently explained. It may be argued that 'healing' is only possible in solidification stage 2, since beyond this stage the crystal formation prevents the free passage of liquid. 'Accommodation' is possible once the dendrites join together, but it really only becomes important in stage 3, where cracks that form cannot be healed (Fig. 2). A more detailed explanation of this figure is given later.

To avoid confusion with the previous concept of the 'brittle range', solidification stage 3 will be called the 'critical solidification range' (C.S.R.) and the temperature of the commencement of stage 3 the critical temperature (T_c). (See Fig. 2.)

As mentioned by other workers, the molten weld pool during welding does not freeze according to equilibrium conditions, and thus it is possible that the liquidus and solidus are depressed by undercooling, and the solidus may be further depressed by the lack of diffusion. The effect of this is to increase the C.S.R. and thus to increase the likelihood of cracking.

Effect of interphase and grain boundary energies (dihedral angle)

For cracking to occur it is not a sufficient condition that a wide freezing range should exist; not only should the alloy pass through a liquid-solid stage, but the liquid should also be present over a relatively wide temperature interval in a form that will allow high stresses to be built up between grains. A liquid phase covering *almost all* the grain faces during freezing will allow the development of high stresses on the narrow bridges joining adjacent grains, but liquid confined to grain edges and corners will prevent these high stresses from being built up.

The distribution of liquid during solidification is related to the physical properties, particularly interfacial energies, of the liquid and solid phases concerned. It must be borne in mind, however, that the process of adjustment to equilibrium conditions is by no means instantaneous and depends very largely on the cooling rate. Under welding (high cooling rates) conditions, near equilibrium values would be established only at very high temperatures.

The significance of the relative free energies of grain boundaries and interphase boundaries in alloys in determining the shape and distribution of micro-constituents has been discussed by Smith[14] but not in relation to casting and welding. The interphase and grain boundary energy is related to the dihedral angle by:

$$\frac{\gamma SL}{\gamma SS} = \frac{1}{2\,\mathrm{Cos}\,(\theta/2)}$$

where γSL = the interphase (solid/liquid) energy
γSS = the grain boundary energy
θ = the dihedral angle

The dihedral angle can be measured from a metallographic section.[14] The ratio $\frac{\gamma SL}{\gamma SS}$ is of particular importance, and for convenience is hereafter designated τ (after Ikeuye and Smith[15]). The dihedral angle is zero for $\tau = 0{\cdot}5$ and all values below. The relation between the dihedral angle and τ for $\tau \geqslant 0{\cdot}5$ is shown in Fig. 3.

It has been suggested[14] that, in alloy systems where extensive solid solutions occur, when the liquid is of substantially similar composition to that of the previously frozen solid, 'wetting' of the grain faces and edges will be almost complete. For this to occur τ must be slightly greater than 0·5. If this condition exists in the weld pool over a relatively large temperature interval while it is freezing then it can be reasoned that cracks could form under adverse strain conditions, because only small areas of the adjacent grains will then be joined. On the other hand, when metals are immiscible in the molten state and one metal solidifies τ will be much greater than 0·5, and the liquid will be largely confined to the grain edges and corners. In these systems the cracking susceptibility would be low.

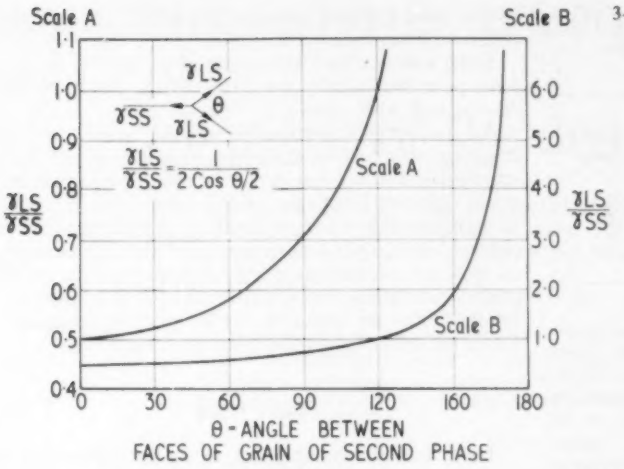
In general, as τ increases above 0·5 ($\theta = 0°$) the liquid progressively occupies less of the grain faces, and at $\tau = 0{\cdot}57$ ($\theta = 60°$) it can exist only as a continuous network along the grain edges. For values of $\tau \geqslant 0{\cdot}57$ the liquid phase will collect at the grain corners and will extend progressively less along the grain boundary edges as τ increases (Fig. 4).

When τ is less than 0·5, however, the liquid is able to penetrate between existing grain boundaries, and in doing so destroys the cohesion between adjacent grains. In this condition, however, the stresses imposed upon the crystals during freezing should be virtually nil.

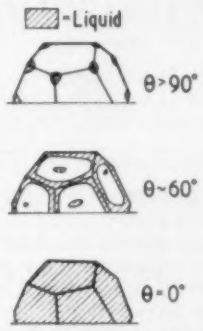
During the freezing process τ increases* (assuming no phase change takes place), and for most alloys reaches a value greater than 0·5 before solidification is complete.

It is now suggested that τ governs the distribution of the liquid during the final stages of solidification

* Owing to change in difference between solid and liquid compositions.



3—*Ratio of interphase boundary tension and grain boundary tension as a function of dihedral angle of second phase*[14]



4—*Effect of dihedral angle on distribution of liquid phase on grain corners, edges, and faces*

(*i.e.*, below T_c) when grain boundaries are being developed. A high value of τ*, say 0·57, manipulates the liquid so as to allow grain faces to join and so provide a strong bond and thus prevent the formation of fissures. On the other hand, a value of τ near 0·5 allows liquid to remain at grain faces as an almost continuous film and prevents them joining quickly; this allows high stresses to be built up locally and fissures to be developed. As a corollary, it may be argued that if continuous liquid films exist then fissures are unlikely to be formed because of the small stresses imposed upon the separating liquid films. Bridging between grains cannot occur, nor can a C.S.R. be established. Ideally, therefore, fissures will not form when τ is less than 0·5. In practice this condition is satisfied only when a pure metal solidifies. Solid solutions should also freeze in the same manner as pure metals but, because of the relatively fast cooling rates, equilibrium conditions are not obtained and τ values of just greater than 0·5 are developed. Solid solutions are, therefore, inherently susceptible to cracking. Only under non-equilibrium freezing conditions.

Generalizing, it might be said that the increasing value of τ with cooling below the critical temperature competes with the increasing thermal strains, and that fissuring is prevented only when the stress imposed on the bridges between the growing dendrites does not exceed a critical amount. The stress is, of course, a function of the grain-boundary area that is joined and not separated by a liquid phase. The distribution and quantity of liquid is influenced by the grain size and shape, and the effect of temperature (and cooling rate) on the slope of liquidus and solidus curves. These slopes in turn determine the composition of the liquid in contact with the growing crystals, and it is the composition of the liquid that largely determines the value of τ. The temperature effect on τ (assuming no change in liquid composition) is probably less than 1 erg/sq.cm/°C. and is no doubt nearly the same as the grain boundary interfacial energy coefficient, which is approximately[16] —0·5 erg/sq.cm/°C.

Under welding conditions it seems likely that the effective value of τ in the C.S.R. is developed during the first few moments of freezing. At lower temperatures equilibrium values would not be established instantaneously, and thus the τ values created at the higher temperatures would persist. For alloys containing small amounts of solute, it would seem that the *initial* slope of the liquidus is very important.

Whether the factors affecting crack propagation are the same as those affecting crack initiation is not quite clear. It is possible that the extent of the C.S.R. below the crack initiation temperature assumes a more important role in crack propagation than the dihedral angle.

Effect of solute additions

The form of the diagram (Fig. 2) showing the cracking tendency in a binary system is due to the following circumstances: With increasing amounts of solute, T_c will be depressed because of the greater amounts of liquid persisting to lower temperatures; at the same time the solidus is lowered due to changes in solid solubility. As the extent of the freezing range thus increases so does the C.S.R. because of the greater amounts of non-equilibrium solidification. The net effect increases the cracking tendency. This will continue until the solidus is not further depressed (limit of solid solubility) and if at the same time T_c is lowered further, cracking will decrease due to the consequent shortening of the C.S.R. Below the solid solubility limit the τ value will probably remain at just above 0·5 but will increase more rapidly as this limit is exceeded and a eutectic composition is approached. It is emphasized however that the establishment of the C.S.R. is due to non-equilibrium freezing and the creation of a τ value greater than 0·5.

Application of Theory

To apply the generalized theory it would be necessary to know the dihedral-angle/temperature relationship under welding (non-equilibrium) conditions. Unfortunately the only information available (and that is small) is the dihedral-angle/temperature relationship for materials under near-equilibrium conditions. Thus only a very limited appraisal of the theory can be offered at the present time.

Experiments[17] on the iron-sulphur system indicate

* For simplicity, assume for the moment that τ changes very little in the C.S.R.

Table I

Relative interfacial energies of liquid sulphide/iron interfaces[17]

Temperature °C	*Dihedral Angle, Liquid versus Fe|Fe*	*Liquid-Iron Interfacial Energy (Fe|Fe=1·0)*	*Fe Content of Liquid %*
1026	30°	$0{\cdot}51_6$	70
1198	25°	$0{\cdot}51_2$	74
1301	0°	$\leq 0{\cdot}50$	78
1325	0°	$\leq 0{\cdot}50$	80

that the interfacial energy between γ-iron and the sulphide liquid is only a little greater than half that of the grain boundary energy at about 1000–1200°C. (Table I). These results might suggest that the presence of sulphur in mild steel would be harmful. This is so, of course.[18,19] In the iron-copper system low τ values ($\sim$0·51) also persist over a significant temperature interval.[17] It is suggested that copper in mild steel can cause hot cracking.[20] At the other extreme, liquid lead, bismuth, and cadmium form dihedral angles of nearly 180°.[17] Despite the very large freezing ranges ($\sim$1000°C.) existing in their alloys there is no strong evidence that these elements are very harmful in mild steel.

In spite of the lack of information on dihedral-angle/temperature relationships, the application of the generalized theory need not be too restricted. According to the theory so far developed, an alloy is highly susceptible to cracking when the composition of the liquid in contact with the growing crystals is similar to that of the solid and changes very little over a relatively wide* temperature interval. Binary systems that to a large extent satisfy these conditions are those which exhibit a small primary solid solution range with a near vertical solidus, and a liquidus which, initially, does not change too rapidly with a fall in temperature. Alloys most susceptible to cracking should be those which contain a small amount of the solute element. Alloys with a large amount of the solute have a liquid composition which is somewhat different from that of the solid.

Some alloys which are expected to, and do in fact, have poor weldability are Fe–S, Ni–S, Ni–P, Ni–Pb, Al-Cu, and Al-Si alloys.

An important implication of the theory is that cracking may be prevented (in susceptible alloy) if the composition of the liquid can be modified so that it is much different from that of the solid. Thus the effect of manganese in reducing cracking in mild steel due to sulphur can, in part, be interpreted[22] as a replacement of iron by manganese in the liquid residing at the grain boundaries. The substitution of iron by manganese will raise the value of τ.[21] To prevent cracking it would be unnecessary for MnS to form.[22]

* 'Wide' here may be a matter of only a few degrees.

Future Work

There remains much work to do in attempting to verify the generalized theory and to put it on a much more quantitative basis—if indeed this can be done—and in particular to correlate the physical properties of alloys with their known cracking susceptibilities. As a start to this work the author[22] has discussed the effect of various elements of hot cracking in mild and low-alloy steels, austenitic stainless steels, aluminium, and copper alloys. In this work the theory is extended to include the effect of phase changes during solidification.

Conclusions

(1) Microcracks are most likely to form when *almost continuous* films of liquid are present, which allow high stresses to be built up on the narrow bridges between dendrites. With less continuous films, higher stresses are required to cause cracking.
(2) The fundamental reason for crack formation is that the liquid composition at the grain faces and edges during initial freezing is nearly (but not quite) the same as the solid just previously frozen.
(3) Cracking may be prevented if the liquid phase composition can be modified so that it is much different from that of the solid.

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DISCUSSION AT THE SYMPOSIUM ON:

Fatigue of Welded Structures

A Symposium on the Fatigue of Welded Structures was held at Cambridge University from 29th March to 1st April, 1960, jointly organized by the British Welding Research Association and the Engineering Department of the University.

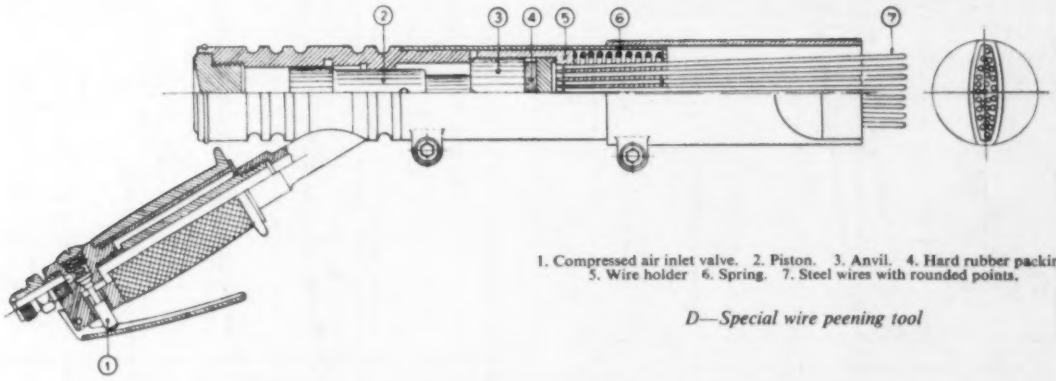
Eleven papers were presented for discussion; these were published in the March and April 1960 issues of B.W.J.

The discussion on the first three papers was published in the July issue of B.W.J. *Further discussion on four papers presented in Sessions III and IV, under the Chairmanship of Professor J. F. Baker and Professor W. H. Munse, respectively, now follows preceded by an addition to Session I.*

Session I

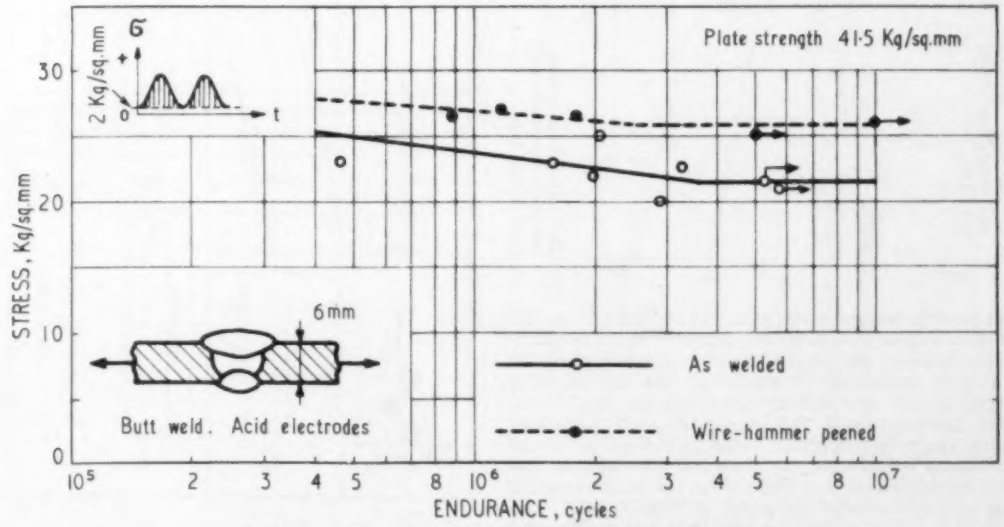
Dr. Ing. Ugo Guerrera (Registro Italiano Navale) wrote: With reference to Mr. Russell's request for information, and Mr. Newman's further comments,* on the fatigue strength of butt welds given a hammer peening treatment, I would like to submit the results of some experiments carried out in Italy by Dr. A. Nacher (Italian Navy).

* This contribution refers to a statement by Mr. Newman during the discussion of papers at Session I (see July *Brit. Welding J.*, p. 475).

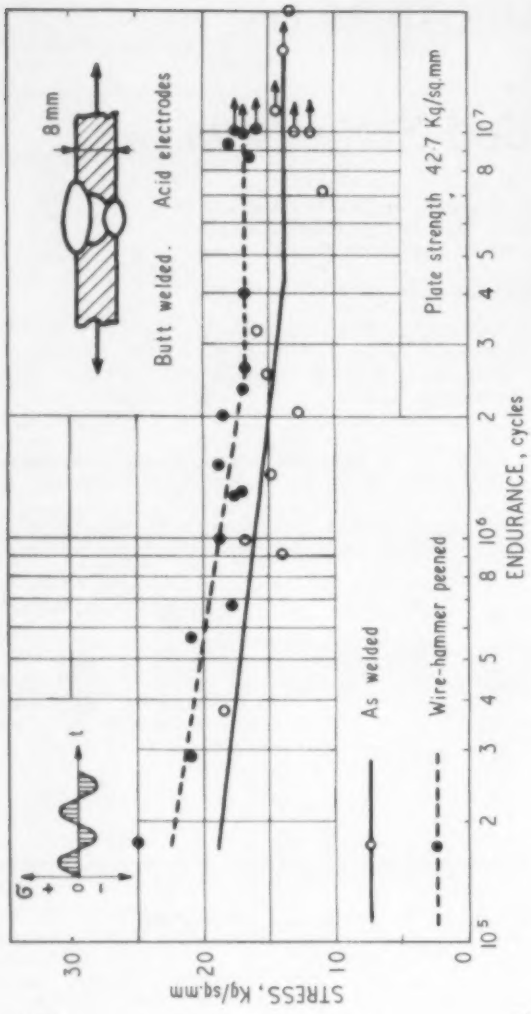


1. Compressed air inlet valve. 2. Piston. 3. Anvil. 4. Hard rubber packing 5. Wire holder 6. Spring. 7. Steel wires with rounded points.

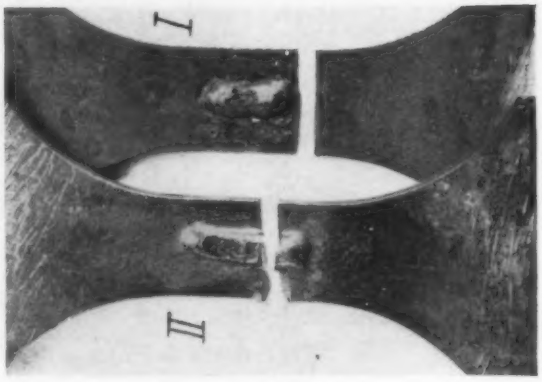
D—Special wire peening tool



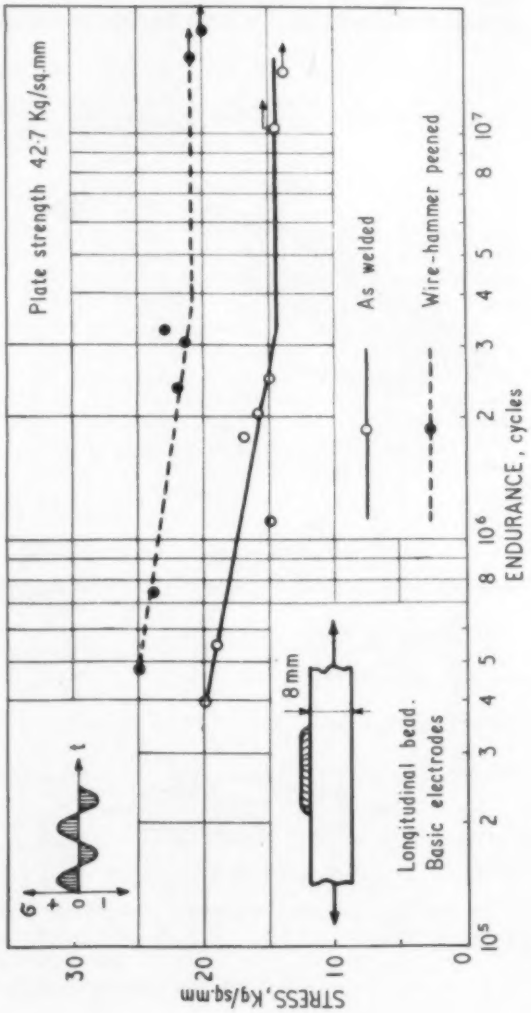
E—S/N curves for as-welded and peened butt welded specimens



F—S/N curves for as-welded and peened butt welded specimens



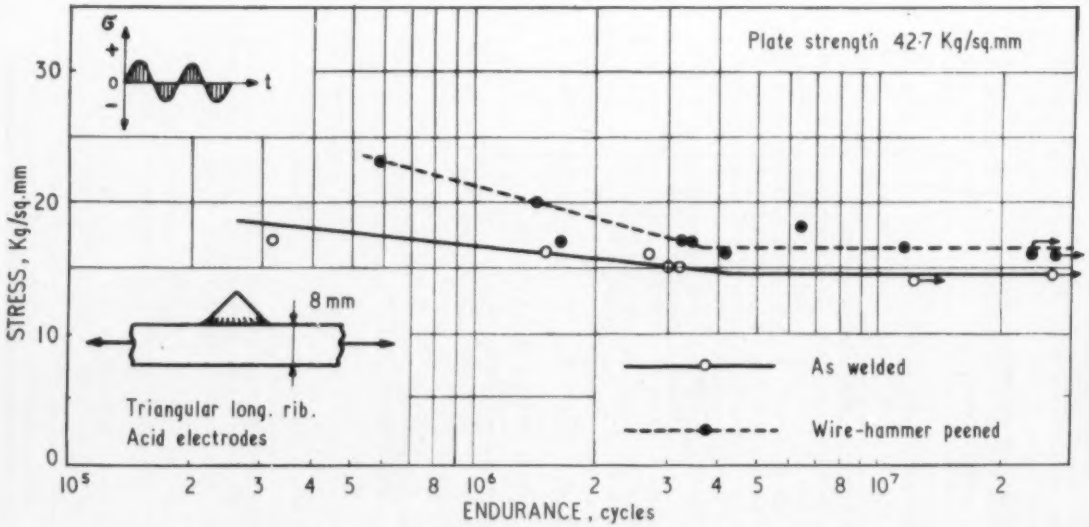
Gb—Fractured specimens with longitudinal bead: I—as welded; II—peened



Ga—S/N curves for as-welded and peened specimens with longitudinal bead

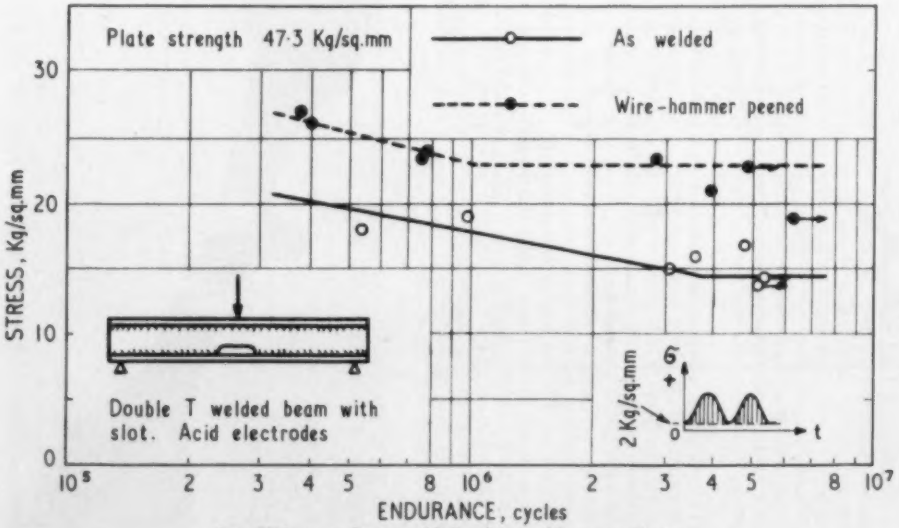
The peening treatment was generally applied all over the weld with a solid, rounded tool mounted in an ordinary caulking hammer, and with a special tool supplied by the firm P. Von Arx-Sissach (Switzerland). This tool contains a bundle of steel wires with rounded ends (*see* Fig. *D*).

With the solid tool, the benefit obtained in fatigue strength was rather doubtful owing to the scatter of the experimental values obtained; with the wire hammer the benefit was quite clear. Examples of the results showing the degree of improvement are given in Figs. *E* to *L*. The various forms of specimen are also shown in the figures; these were usually about 1 in. wide.



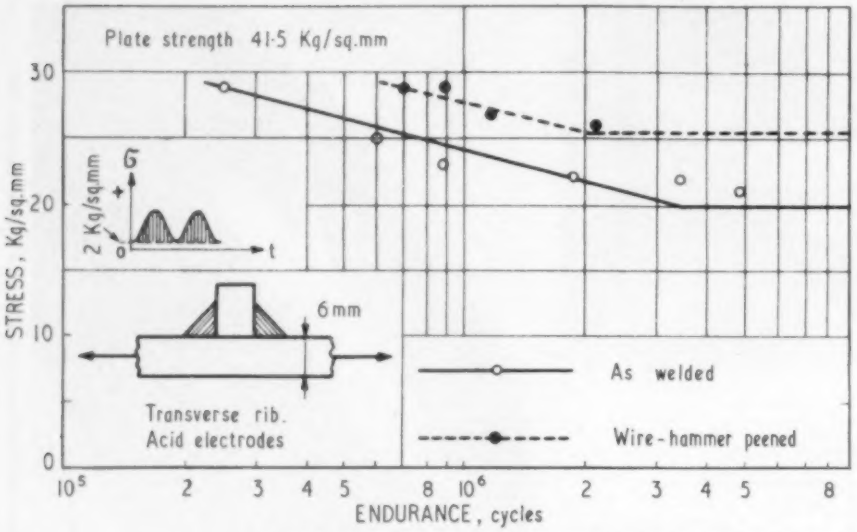
Ha—S/N curves for as-welded and peened specimens with longitudinal rib

Hb—Fractured specimens with longitudinal rib: I—as welded; II—peened

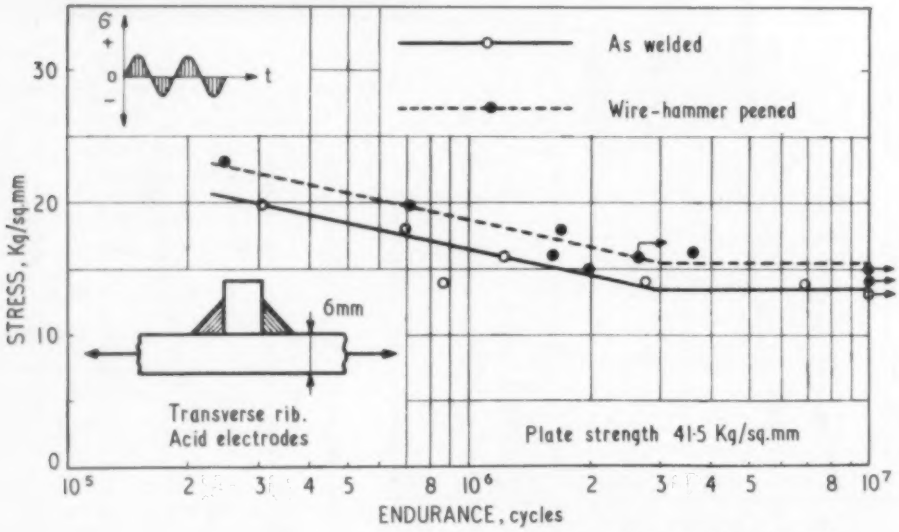


Ja—S/N curves for as-welded and peened beam specimens

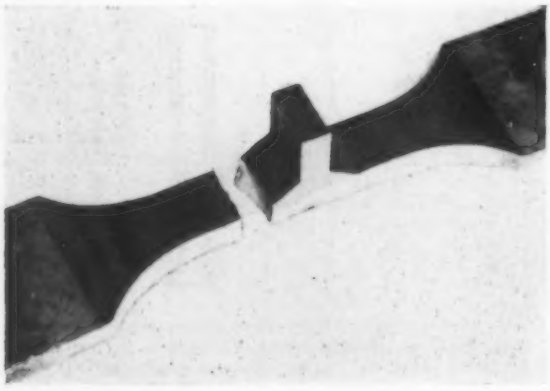
Jb—Fractured beam specimens: weld peened near cope hole



K—S/N curves for as-welded and peened specimens with transverse rib



La—S/N curves for as-welded and peened specimens with transverse rib



Lb—Fractured specimen with transverse rib: weld peened

Session III

Influence of Weld Details on the Fatigue Strength of Welded Beams and Girders *By W. H. Munse and J. E. Stallmeyer*

Programmed Fatigue Testing of Full Size Welded Steel Structural Assemblies *By J. G. Whitman and J. F. Alder*

Professor Munse (University of Illinois) introduced the first paper and **Dr. Whitman** the second. Dr. Whitman (Military Engineering Experimental Establishment) noted that one of the encouraging features of the programme loading tests done so far was the observation that rate of crack propagation was slow. Final failure never took place in less than 100,000 cycles from the time the crack was visible to the naked eye, and in one programme test the crack existed for 900,000 cycles. It was significant that, when Bailey Bridges were used for civilian purposes, the lowest stress of the particular programme used would normally correspond to a 20-ton vehicle. Thus, 100,000 crossings of such vehicles and heavier would take a very long time; in fact, if one took an average density of one such vehicle every two hours, the crack would be visible for a minimum of 23 years! It was known, moreover, that in the light sections concerned, the crack would have to be quite large for brittle fracture to occur at low temperature, so that there would be time in hand for the cracking to be detected.

Dr. Whitman went on to say that three more experimental points could be added to the right-hand top group in Fig. 8* (results of programme tests). These were: (i) A fracture after 345,000 cycles with a maximum stress of 15·1 tons/sq.in.; (ii) two specimens unbroken after 2×10^6 cycles at maximum stress levels of 11·0 and 11·7 tons/sq.in. (*See* revised diagram Fig. *M* which also contains two later results reported after the symposium. The Addendum to Table III(*a*) gives a complete record to date.) With reference to measurement of load spectra, Dr. Whitman said that observations on four trunk road bridges were now being made. So far, live load stresses had not exceeded 1 ton/sq.in. on one bridge and 0·5 tons/sq.in. on the other three. It was most unlikely that stresses of this order would be significant in the context of fatigue, even after a crack had been initiated, and it was probable, therefore, that the problem of the estimation of numbers of cycles of load could be narrowed to the heavier and more unusual types of vehicle of the rarer combination of these.

Mr. O. A. Kerensky (Freeman, Fox and Partners): Having read the various papers and listened to the discussions so far I, as a mere designer, feel some apprehension and depression. I should like to remind you that high-tensile steel was developed at the instigation of bridge builders and that we cannot build long span bridges without it. In about 1880 the Forth railway bridge was built by Benjamin Baker, using high-tensile steel with some allowance for fatigue. I would emphasize that although we must make all possible provisions for estimating the life of a high-tensile steel bridge, there can be no question of abandoning this material for large structures. Therefore the designer must have precise guidance on the details of construction that are acceptable and on the allowable stresses that can be used for both mild and high-tensile steels.

Most of the research work has been done for the zero-to-tension cycle; whereas, as Professor Munse has said, in large bridges the cycle is more likely to be in the range $\frac{1}{2}f_{max}$–f_{max}, to $\frac{3}{4}f_{max}$–f_{max}. Can we get more experimental results in this sector and develop a better idea of the precautions we must take when large dead-load stress, in tension and compression is present? Half of a bridge consists of compression members; need we take precautions with these in respect of fatigue? Again, we need guidance. We are also not very clear about what to do when compression predominates but there is a reversal into low tension. For example, at the present time most specifications would give the same stress reduction coefficient for load cycles that produce +8 to −2 tons/sq.in. and −8 to +2 tons/sq.in.; can this be substantiated?

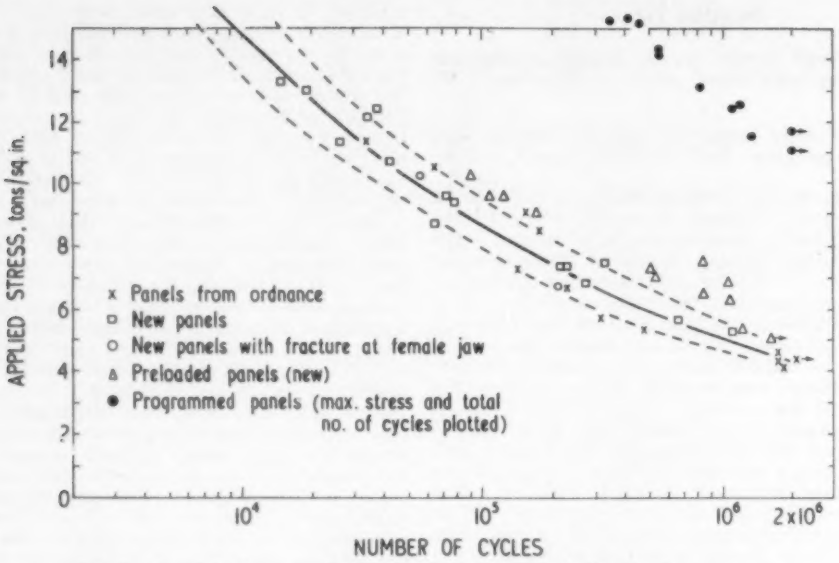
Should we abandon certain welds altogether? If so which? The American paper presented today has introduced the question of principal stress, as far as I know for the first time. Hitherto the influence of shear has been ignored. And yet the test results indicate failure at about 5 tons/sq.in. principal stress, a figure which in the modern design of plate girders with their thin webs must be produced every time. Does this mean that stiffeners are useless, unless they are attached by bolting or riveting; or perhaps welded and covered with plastics! Moreover, the failures have sometimes been located well away from the tension flange, whereas in design we have concentrated only on the avoidance of the flange-to-stiffener connection. And we are told by research workers that this state of affairs would apply equally to mild and high-tensile steels. It seems to me then that we have to design plate girders without stiffeners, or we have to find some way of treating the stiffener connections, for example, by spot heating. This kind of conclusion comes as something of a shock.

One might perhaps be more optimistic about continuous, longitudinal welds such as are used for making up box-section members in large trusses. Such a member, constructed from, say, four plates with corner welds would appear to be less prone to fatigue troubles because, we are told, the so-called non-load-carrying weld that is longitudinal and continuous is less harmful in its strength reducing effect. If this is the case we might visualize welding being confined to the shops and site connections being made with high-tensile bolts, which, I believe are capable of giving economic construction.

Table VI of the paper indicates a fatigue strength of 11½ tons/sq.in. for a mild steel plate girder with continuous web-to-flange fillets. This suggests that if one could get 12 tons/sq.in. for a high-tensile steel girder, higher working stresses could be used. This small increase would bring one into the region where BS. 968 could be used economically, since BS. 15 construction would not be stressed above 10 tons/sq.in. Thus there would be a ray of hope for high-tensile steel provided that one could avoid the apparent damaging effect of the welded stiffeners. What I would like to know is whether there are any examples of riveted or bolted stiffeners failing from the hole nearest to the flange at a stress of 5 tons/sq.in. If there are no such examples, this type of stiffener attachment might therefore be considered, or, more accurately, brought back into use. It would at least encourage the machine welding of the web-to-flange connection which, I believe, gives the best results.

The paper by Dr. Whitman and Dr. Alder is more cheerful in its outlook, in that these authors appear to be suggesting that highway bridges, designed to British Standards, are not likely to suffer from fatigue. Their work is not yet conclusive, but this view is one that many of us have supported for a long time. I have heard of cases of designers designing steel girders for 2×10^6 cycles of HA loading. Now HA loading represents an exceptionally heavy concentration of loads and if one takes the figures given to us by Dr. Whitman one comes to the conclusion that this particular loading could be practically ignored. This is what some designers have already tentatively concluded, and it is most important that a proper understanding of loading should be developed. The matter is urgent. Hundreds of bridges in concrete and steel are being erected in Europe and America, and steel is being

* Arabic numerals refer to Figures in the original papers; similarly, roman table numbers refer to the originals.


APPLIED STRESS, tons/sq. in.
NUMBER OF CYCLES
x Panels from ordnance
□ New panels
○ New panels with fracture at female jaw
△ Preloaded panels (new)
● Programmed panels (max. stress and total no. of cycles plotted)

M—Results of further tests. Dashed curves are at 2|3 and 3|2 life of mean curve

handicapped by fatigue allowances which, by some mysterious process, the concrete construction escapes.

The problem with railway bridges is rather different. Such bridges will be getting the stresses they are designed for, with the development of diesel and electric locomotion, and the load spectrum will be much flatter. For short-span bridges, fatigue design may well be obligatory and the chances of using high-tensile steel obviously reduced. But I do not think that this steel will be abandoned in any other bridges.

Finally, I have heard it mentioned that one should consider introducing a factor on actual fatigue strength. I submit that by the use of what is already a reduced stress, the fatigue limit stress, we have already taken the precautions necessary to stop a structure falling down within its planned span of life—which will be very long. Factors of 1·2 and 1·5 have been mentioned, and I would like this conference to consider whether these are justified. In the British Standards committee we did not think so and we have not applied any factors against what we thought at the time were the fatigue limit stresses.

Professor Munse: I would certainly be in agreement with many of the comments offered by Mr. Kerensky. I would like to point out, however, that the results about which we have been talking are primarily for zero-to-tension loading; many bridges do not have this type of loading, so the picture may not be quite as bleak as he has indicated. The fatigue strength of the splice member in Fig. 23, for example, is certainly up at high stress levels for $f_{min} = \frac{1}{4}$ or $\frac{1}{2} f_{max}$. When we get into the other part of the diagram the line extends down to about 10,000 lb/sq.in., in full reversal, and this may be a problem to worry about when splices in continuous girders are placed at points of inflexion where stresses are low but reversal occurs.

Another point that has been mentioned concerns the matter of compression. Referring to Fig. 10 this is a good indication of what can happen in laboratory testing of welded members. Notice the failure in the compression flange at the top of this member; this propagated very slowly, but did initiate first. As the test was continued another crack developed outside the load point to the left of the member at the web weld and then the major failure developed in the lower tension flange at the splice joint. Three cracks developed in the member at three different places all in the same test. Many questions have been asked about the compression failure. One suggestion is that this is a result of the combined stress in that flange. Here I believe the web was welded first when the staggered splice was made. The flange welds would therefore be subjected to residual tension. Under loading, the compression flange could thus have suffered a reversal of stress and this might have been a factor in the failure of this flange. Tests to study the behaviour of similar members under a variety of stress ratios are under way at Illinois and we hope soon to be able to answer Mr. Kerensky's questions on this matter.

It is often said that design stresses for bridges are now so low that there cannot be a fatigue problem. However, in the State of Ohio failures in many highway bridges are being recorded. These bridges were designed some years ago for relatively light loads. These loads have increased over the years and fatigue failures are now being observed. Usually the spans are short and the stress range, under present loadings, are quite significant. In considering design stresses, therefore, the question of future loading is sometimes not unimportant.

Regarding the influence of stiffeners in shear areas, Table IV gives the results for three of the members shown in the photographs. The centre member failed at almost 2×10^6 cycles with a maximum principal tension stress at the failure section of about 19,000 lb/sq.in. The shear in the web at this point of failure was 14,000 lb/sq.in., a relatively low value which suggests that we should give more consideration to the matter of shear, particularly in some of the large girders with relatively thin webs.

Dr. Whitman: Mr. Kerensky has mentioned the question of live-load to dead-load ratio. I think I speak for all research workers in saying that the need for studying the influence of such ratios is fully appreciated. What is required is a Goodman type diagram for all the joint forms which have been referred to. This obviously involves a great deal of work and would cost a considerable amount of money, and we must have financial help from industry if we are to provide complete information of this nature.

Mr. Kerensky also mentioned railway bridges. We agree these are quite a different problem from road bridges, particularly in regard to design requirements in this

country. However, in two-line railway bridges it would require something of a coincidence to have two trains crossing the point of maximum bending moment simultaneously, and exerting their maximum impact effect at the same time as other loads (*e.g.* wind) were also at a maximum. In such a case the maximum design stress obviously does not occur so frequently. Single-line railway bridges are, of course, a different problem and so are the deck members themselves.

I agree with Mr. Kerensky's remarks on the safety factor. I have always regarded the safety factor as something affected by time as well as stress. The safety factor against failure by corrosion is a time consideration; I see no reason why this should not apply to fatigue as well.

Mr. Berridge (British Railways, Western Region): I too have been feeling rather pessimistic since reading the admirable paper by Munse and Stallmeyer. We cannot stand still in the design and renewal of railway bridges in this country. There are not enough riveters left to make them of riveted construction and we have to make use of welded plate girders for the moderate spans that are usually involved. I would say that the fatigue life of welded plate girders is affected by three things:

(i) Geometry of design
(ii) The magnitude of residual stresses in the fabrication
(iii) The perfection of the welds.

BS.153 is I think silent about the ratio of thickness of flange to thickness of web. I wonder whether Professor Munse would think it would be a good thing to alter this to ratio of flange area to web thickness. I would say, dealing first with flange-to-web fillets, it is essential to complete the butt welds in both the flanges and the web before marrying up the flanges and webs. Did this apply in the American tests?

Secondly, it is very essential to avoid interruptions when depositing the web-to-flange fillet welds. We specify that these welds should be made by an automatic process to avoid the stopping and starting that occurs every time a hand operator has to change his electrode. It follows from this that stiffeners will have to be added after the flanges and webs are assembled. Incidentally if you add the stiffeners to the web after you have made your beam the residual stresses set up in the web-to-flange fillets are opposite in sign in the tension flange to the horizontal shear you get under load.

Figure 16 of Professor Munse's paper would appear to favour welding the stiffeners to the bottom flange! Prior to revision of BS.153 we always did weld the stiffeners to the bottom flange because of certain mechanical requirements. Now, however, we toe the line in order to use higher stresses in the flange. [Mr. Berridge went on to illustrate these points with slides of typical railway bridge details, showing, in particular, the connection of cross-girders. The earlier designs incorporated stiffener-to-flange welds where the cross-member was attached to the stiffener. To accord with BS.153, later designs eliminated this welded connection, and to stabilize the stiffeners horizontal gussets, welded to the web and stiffener end, had been added.]

Professor Munse: These comments add a great deal to the discussion we have already had this afternoon. Concerning the relationship between flange and web, we started discussing this matter in terms of thickness and this is the principle reason for carrying the idea through. There may be a better relationship with the flange area but up to this point we have been thinking of the relative thickness of flange and web. Many of the tests have been conducted with a constant flange thickness and a varied web thickness, since this offered a more simple way of analysing the data.

Considering the welding sequence in the spliced members, some of the tests were made with the flange splice made first and the webs welded later. This was thought to give a better state of residual stress in respect of fatigue behaviour. However, engineers have told us that fabricators would not do this but would want to weld the splice in the web first so as to have a more stable web for the setting up and alignment of flanges. Our sequence in these tests then has been dictated largely by what fabricators would prefer to use and not necessarily by what might be thought to be the best laboratory procedure.

With regard to the possibility of automatic welds being better than manual welds, we have found that automatic welds developed fatigue failures at the points where tack welds were placed, and did not show much difference from manual welding in fatigue strength. In any case the fatigue

Addendum to Table III(a)

Results from tests with varying load amplitudes with a predetermined programme. (Quadratic type)

Specimen	*Maximum Nominal Stress, tons/sq.in.*	*No. of Cycles at Stress* n*	*Expected Life at Stress N*	*Ratio* $\frac{n}{N}$	$\sum \frac{n}{N}$	*Total Cycles in Test*
G17A[a]	3·5	41,000	Infinite†	0		
	5·5	26,600	650,000	0·041		
	6·8	13,700	280,000	0·049		
	9·2	5,000	80,000	0·062		
	10·6	720	42,000	0·017		
	11·7	27	28,000	0·001	1·9	345,102
	3·7	126,100	Infinite	0		
	6·6	75,900	315,000	0·241		
	9·7	39,400	63,000	0·625		
	12·4	14,250	21,300	0·669		
	13·9	2,330	13,000	0·179		
	15·1	75	9,200	0·008		
11A[b]	3·3	980,600	Infinite	0		
	4·7	594,800	1,250,000	0·476		
	6·7	305,400	300,000	1·020	2·9	2,009,823
	8·7	112,400	105,000	1·070		(unbroken)
	10·2	16,020	52,000	0·308		
	11·7	603	27,500	0·022		
11B[b]	3·1	980,600	Infinite	0		
	4·5	594,800	1,600,000	0·371		
	6·3	305,400	375,000	0·815	2·3	2,009,823
	8·2	112,400	130,000	0·865		(unbroken)
	9·6	16,020	68,000	0·238		
	11·0	603	36,500	0·016		
12A[b]	3·0	401,000	Infinite	0		
	5·0	243,900	940,000	0·259		
	7·5	125,000	195,000	0·641	2·1	822,596
	10·4	45,850	48,000	0·955		
	12·0	6,600	24,800	0·266		
	13·0	246	17,000	0·014		
12B[b]	2·8	564,500	Infinite	0		
	4·7	340,800	1,250,000	0·273		
	7·1	175,500	240,000	0·731	2·3	1,155,112
	9·7	64,900	65,000	0·998		
	11·3	9,070	32,000	0·284		
	12·3	342	22,000	0·016		

* Total cycles at each stress level.
The loads applied are distributed in as random a manner as practicable.

† Assumed to be infinite.

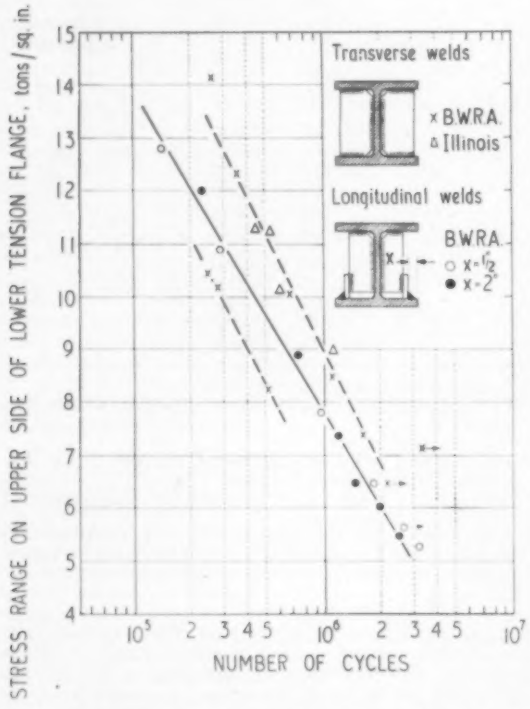
[a] This specimen was a new panel and was used in two programmes, a short one with a peak stress of 11·7 tons/sq.in. and then until failure in a programme with a peak stress of 15·1 tons/sq.in. as shown.

[b] These panels were from Ordnance. (The last two results were obtained since the Symposium was held and are given here as further support for the results presented at that time).

resistance of the fabricated member is high and if we had loading cycles more typical than the zero-to-tension case then the fatigue strength will be considerably higher.

Mr. Gurney has checked the calculations and there are some errors in calculated values for principal stress. These will be checked and we may find that some corrections will have to be made. However, I think the general picture is as shown in the diagram, and it must be remembered that many failures shown in Figure 16 occurred in stiffeners out near the ends of the span, whereas when they were connected to the flange, failure was always initiated in the pure moment region.

Mr. Gurney (B.W.R.A.): I am surprised to hear of the failures from tack welds in the web-to-flange connection. One would have thought that the automatic welding would have effectively obliterated these tacks. The tests of BS.968 beams now in progress at B.W.R.A., which Mr. Newman referred to this morning, are tending to confirm that automatic welds are superior to manual welds. The latter are failing from start/stop positions; partial penetration automatic welds fail from the root, and full penetration automatic welds have so far not failed from the weld at all. A preference for full penetration automatic welding might therefore be stated, and this should certainly be considered in relation to the problem of local stressing of the top flanges of gantry girders due to crane wheel loading, mentioned by Mr. Lewis.



N—Fatigue test results for beams with stiffeners welded to flanges

With reference to beam splices, I would suggest there is not much difference between the various forms given in the paper. Possibly the most important point, however, is hidden in the proviso that one must take care in extrapolating from laboratory tests to actual structures. There can be little doubt that a poor butt weld in the tension flange without a cope hole is a worse condition than a good splice with a cope hole; in fact if fatigue cracking is possible, it would be better to have this in the web rather than in the flange. In this respect there is some point in considering the effect of varying the shape of cope holes and of producing a rather better finish in the cope hole than gas-cutting; this might be an economic proposition.

As Mr. Kerensky has said it is very easy to get 5 tons/sq.in. principal stress in webs. This can be shown by plotting curves of fixed principal stress values on a diagram with bending stress and shear as the parameters. At B.W.R.A. we have not studied the attachment of stiffeners in shear areas, but some work has been done on rolled sections with stiffeners in a pure moment region, attached to the flanges either with transverse or longitudinal fillets. The results, shown in Figure *N*, appear to be complementary to those given in the paper by Munse and Stallmeyer. Two longitudinal weld details were tested, the difference between them being the distance from the edge of the flange to the attachment weld. The plotted points show that this variation has no effect on fatigue strength. The dashed scatter band refers to transverse welds; the degree of scatter here appears to depend upon operator skil!, especially with respect to undercutting. The lower limit, some 2 tons/sq.in. below the upper limit at 2×10^6 cycles, was given by specimens made by one welder and containing very slight undercutting which, nevertheless, resulted in the 30% loss of strength.

Also plotted in Fig. *N* are four results that were made known to us by Professor Munse; these refer also to transverse attachment welds on the tension flange, and the results correspond well with the upper limit of the scatter band. Taking these results as a whole, I cannot readily accept Table VI of the paper, which suggests a fatigue strength of about 10 tons/sq.in. for a beam with stiffeners; I would divide this value by two!

Referring back to Mr. Kerensky's remarks on the use of high-tensile steel for plate girders, the tests on BS.968 specimens, made by continuous, automatic welds, are giving rise to reasonable hope that the strength values he requires will be exceeded. Undoubtedly then, the main problem is the one of stiffener attachment.

Professor Munse: I am happy to hear that automatic welding has shown improved fatigue resistance in the B.W.R.A. tests. The results I mentioned were for a small number of tests, and there may have been a somewhat different procedure used in fabricating these members which could account for the difference in behaviour. This is something which should be pursued further. With regard to cope holes; when these were used at the flange splice, most of the failures were not in the cope hole itself in the web but at the toe of the weld which joined the web to the flange. Some variation in cope hole geometry might have improved the situation when web failure did occur, but clearly this would not affect the principal mode of failure, namely where fracture of the flange was involved.

Concerning the last point raised by Mr. Gurney, the value of 23,000 lb/sq.in. presented in Table VI was taken from the maximum flexural stress values shown in Figure 14. You will see in this figure that at 2×10^6 cycles the average value is about 23,000 lb/sq.in. This is the maximum flexural stress and not the maximum principal stress.

Mr. T. Haas (B.W.R.A.): First of all I should like to congratulate Dr. Whitman and Dr. Alder on the excellent piece of work done; they have undoubtedly pioneered in this country a new and significant method of testing welded structures. It gives me great pleasure to be able to contribute some comments on their paper because I, myself, had the good fortune of having been able to carry out similar tests on bolted and riveted designs[1] three years ago.

An enormous literature has grown on the subject of cumulative damage from which it is only too painfully clear that none of the many "laws" formulated have, or

possibly could have, taken account of the chronological sequence of the load cycles of varying amplitude occurring in actual service. The varying mechanism of damage due to such different load sequences is referred to as "load mixing effect", but this effect has so far shown no respect to those who tried to treat it theoretically. It is now sufficiently well known, but not generally accepted, that if realistic test methods are stipulated, the constant-amplitude loading method, *i.e.*, the conventional fatigue testing method, is only realistic if that loading condition is the one met with in service. Programme fatigue testing is not a new testing method—in fact, it was originated by Dr. Gassner[2] over twenty years ago.

Surprisingly, there are still many experimenters who seem to be guided by the proverb "half a loaf is better than none"—by this they consider constant-amplitude testing to be better than none. However, if constant-amplitude results are compared with both service experience and spectrum test results, in very many cases this does not appear to be so. It would certainly not be true to say that half a bridge is better than none—not when the other half is broken!

The authors have avoided the pit-falls of these and of other half measures. They have taken into account the size effect and the environmental conditions. They have taken as complete a bridge as is necessary to have structural interactions represented, and loaded it with the complete service spectrum. This is a fundamental point because half the spectrum is not necessarily better than none. It must be the complete spectrum. Incidentally, the simile between loaf and bridge is Professor Gumbel's in the context of the "Statistics of Extremes"[3] which latter subject deals with the occurrence and prediction of extremely infrequent events such as, for instance, the highest loads occurring in the intended life of a bridge. The effect of these highest loads in the presence of *all the other loads* occurring gives programme test results a unique significance. The same, if not greater, significance attaches to the very low loads at the other end of the spectrum. For instance, as Professor Freudenthal[4] has shown, even if one designs for 99·9% of all the loads in the spectrum to be below the conventional fatigue limit, the 0·1% of loads above that limit reduces it by at least 15%, and possibly by as much as 35%. In other words, in the presence of variable stress-amplitudes of which even a very small number is above the conventional fatigue limit, on the average, the effective fatigue limit may be 25% lower than the conventional one. This particular case well illustrates the futility of the various cumulative damage hypotheses known so far, and points clearly towards the need for programme or generally spectrum testing.

In the authors' work the fatigue limit was 4–4½ tons/sq.in., whilst the lowest stress level was between 2½ and 3 tons/sq.in. Thus, their lowest stress level could be assumed as significantly damaging, without perhaps necessitating the inclusion of still lower levels; but this issue will be clarified by the fundamental tests they are conducting. The summation of the cycle ratios to failure varied between 0·75 and 2·8, *i.e.*, as 1:3·7; there were too few results to enable reaching conclusions, but in the light of other published programme results they tend to discredit the linear cumulative damage rule.

The prerequisite for spectrum testing is the availability of the spectrum. As indeed this is also the case for cumulative damage calculations based on S/N tests, possibly the greatest service to progressing towards a definite solution in the problem of finite life design would be rendered by a systematic recording and collation of service spectra. Professor Pope[5] stressed the importance of doing so three and a half years ago. The B.W.R.A. is mindful of this need, and given the necessary encouragement by its members could contribute substantially in the work, for it has already a mobile stress analysis laboratory available which is employed in taking on-the-site strain recordings. The major decision to be made concerns the quantities that should be measured; whether, as the authors did, strain range counters should be used, or counts of exceedances of discrete strain thresholds, or a number of other possibilities be employed is a matter for early decision.

The authors themselves stated that they told only half a tale; I am sure you will agree that we have heard a most interesting half-tale and I am sure we all look forward to and shall be very anxious to listen to the rest of it.

Coming now to the paper by Munse and Stallmeyer, I should like to question the applicability of constant stress-amplitude results when variable loading is present, not so much to the prediction of the life of welded joints, but rather as a basis for making detail design decisions. In other words, the S/N type of data may not be a criterion for structural behaviour in service.

From the published work of the authors[6,7] it is known that they have investigated these problems, and Professor Munse[6] has shown, for bolted joints, that Miner's cumulative damage rule did not agree with his test results, but an exponential damage summation did fairly well. Which damage hypothesis would they use for the splices shown in Fig. VI of the paper?

I am asking this because I do not think that a direct design decision is possible on the basis of the S/N curves shown in Fig. 7. At 30,000 lb./sq.in. splice type *D* is 100% better than type *E*; at 25,000 lb./sq.in. *E* is about 50% better than *D*; whilst at 2×10^6 cycles *D* is 17% below the fatigue strength of *E*, if constant amplitudes are considered only. For a given applied stress spectrum a lot of computing would be necessary before a decision could be made that would be still as much removed from service reality as the cumulative damage rule used would be in error. Would the authors agree that spectrum fatigue data for, say two limiting spectra, are the data needed by designers?

Dr. J. F. Alder (M.E.X.E.): I would like to comment on two of the points mentioned by Mr. Haas. The first concerns the question of whether, in recording the load spectra, one should measure strain ranges or discrete levels of strain. I think we have seen in a number of the papers that the allowable range of stress does not depend critically on mean stress. If, therefore, we measure strain ranges we should get quite close to the answer we want, namely what is happening to the bridge. The question of measuring discrete levels of stress is a much more complicated one, and for this reason we have selected the simpler proposition of recording strain ranges, since the answer should be sufficiently accurate for our purpose.

Mr. Haas also mentioned the B.W.R.A. mobile stress-analysis laboratory. It might be of interest to give a little more detail of the records obtained from the bridge on which we observed a maximum stress of 1 ton/sq.in. Taking this stress as equivalent to level 5 on the indicator, the following totals were achieved during a five hour watch on the bridge:

Level 5 – 5
Level 4 – 16
Level 3 – 46
Level 2 – 56
below Level 2 – 52 (measurable).

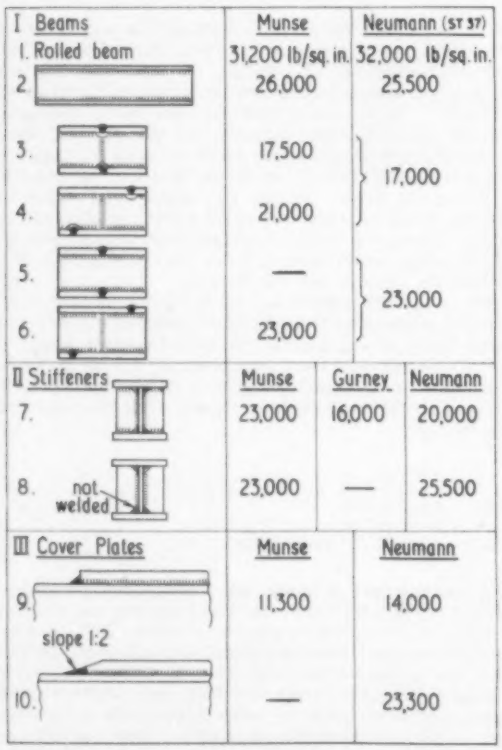
A more intensive count was taken over a half-hour period, during which time one level 5 reading was obtained. A total of 264 vehicle crossings occurred, 50% of which were private cars making no record at all. Actually only 42 of the 264 gave a record (level 5 – 1, level 4 – 4, level 3 – 9, level 2 – 10, level 1 – 18). It would appear that the mobile laboratory would have to be by a bridge for a very long time to get a sufficiently representative spectrum. The idea of installing a counting instrument which can be checked periodically does appear to be the more practicable.

Mr. Haas: May I say that we had no intention of spending weeks on site getting strain records. After strain gauging, the recording instrument would be left to accumulate the stress data over a suitable period of time.

Professor Munse: The question of the relative behaviour of the splice details is an interesting one. Figure 7 shows that the curves for the staggered splice details, types *E* and *B*, are parallel with the cope hole detail, type *B*, slightly lower. The same kind of result applies to the two specimens with the splice made on one plane, types *A* and *D*. Here again the S/N curves are parallel with the cope hole detail, type *A*, slightly lower. However, the S/N curves for *A* and *D* are on a different slope and cross those given by *B* and *E*, suggesting that the manner in which the splice is made has a general influence on the S/N curve. Whether this kind of behaviour would be important when random loading was involved cannot be answered, but on the basis of the evidence available one might suggest that differences between details could be possible, depending on the kind of spectrum applied. This, however, is a very tentative observation.

Dr. J. S. Terrington (B.I.S.R.A.): Could Dr. Whitman and Dr. Alder give us some particulars of their counting strain gauge? At B.I.S.R.A. we have been developing one and have made measurements on electrical overhead travelling cranes and on crane gantries. We should be interested in some of the details of their instruments. They have four levels and we have something like eight.

In concluding I would endorse their experience that actual stress levels or stress ranges so far obtained have been found to be much less frequent in the higher ranges and much more frequent in the lower ranges than one would imagine; design may therefore often be undertaken on the basis of severer loading conditions than would actually be obtained in practice.



O—Comparison of results for $f_{min}/f_{max}=0$ *(*2×10^6 *cycles)*

Dr. Alder: The strain range counter we are using is commercially available and was developed for the aircraft industry. I have not seen the inside of one of these gauges but I understand it is essentially a piston, carrying four collars which are held by friction. These can move within limits. When the limit of travel in one direction is reached the collar slides on the piston but as soon as the piston reverses the collar moves back with it, to the other limit stop. Hitting the first stop cocks a relay, and hitting the other stop triggers it. A complete movement gives you one count. These require 24 volts supply and can thus be completely self-contained for site use.

Mr. A. Neumann (Z.I.S. Halle): It may be of interest to compare the results reported by Professor Munse with the results of fatigue tests we have carried out on similar types of beam member. Figure *O* conveniently summarizes the position and it will be seen that, in general, the degree of agreement is very good. In the case of the splice joints 3 and 4, however, we get the same strength value of 17,000 lb./sq.in. and I do not understand the reason for the difference in strength between these two details given by Professor Munse. In each case we found that failure occurred in the flange at the point where the web-to-flange fillet weld terminates against the edge of the cope hole. There is reasonable agreement between the stiffener details, although here Mr. Gurney has reported lower results and his figure applies also to longitudinal fillets attaching the stiffener to the flange.

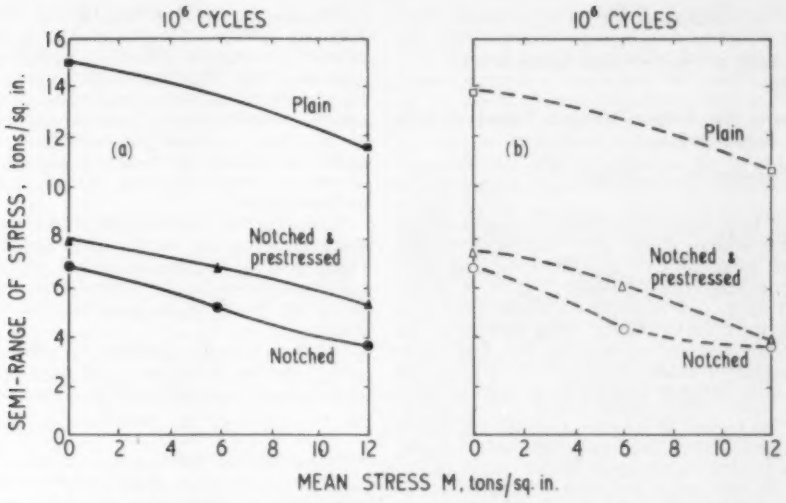
With regard to cover plates, we use a feathered edge cover, with a machined slope of 1:2, for bridge construction. As shown in Fig. *O* the fatigue strength of the beam is markedly better with this detail than with the square-ended cover plate. Is the improved type used in other countries for bridge work?

Professor Munse: I think we should have stopped testing when we got to the cover plates! The agreement between the first groups of figures is most gratifying. Returning to the cover plate problem, I do not think it is surprising to find the large variation. We have conducted a number of other tests with feathered edge cover plates and have found some increase of strength. However, we have also found some values with straight cover plates that were below 11,000 lb./sq.in. and I think there is a lot more to study on this problem of partial length cover plates; for example, the arrangement of welds, welding sequence and the relative thickness of the cover plate and flange may all have an influence.

Dr. Ing. Ugo Guerrera (Registro Italiano Navale) (in a written contribution): With reference to Mr. Neumann's comparison of the fatigue data from his own tests of welded beams wih those reported in Professor Munse's paper, it may well be of interest to draw attention to the fact that a comparison of existing data on the widest possible scale is being undertaken by the International Institute of Welding. The work was started with a collection of existing data from fatigue experiments carried out up to the present time in laboratories of member countries. Full details of each experiment are required and these are carefully studied. The results of this comparison are to be published in appropriate form for the use of designers.

The I.I.W. is also preparing a code of practice on the design of welded structures, two chapters of which are devoted to the comparative ability of welded joints and attachments to withstand fatigue loading.

Mr. K. W. Gunn (Aluminium Laboratories Ltd.): Dr. Whitman and Dr. Alder mention in their paper the effect



P—Effect of mean stress on fatigue strength of pre-stressed notched test pieces: (a) *BS.L65, fully heat-treated, 30 tons/sq.in. 0·1% proof stress, 34·5 tons/sq.in. U.T.S.;* (b) *BS.L64, naturally aged, 22·5 tons/sq.in. 0·1% proof stress, 32·5 tons/sq.in. U.T.S.*

of high pre-loads before beginning the fatigue tests and say that two investigators disagree. One finds that the application of pre-load increases the fatigue strength, the other finds it makes no difference. The results of an investigation of high-strength aluminium alloys (BS. L64 and L65) show that, after pre-loading, either an increase or no change in fatigue strength can occur depending on the stress conditions. These results are shown in Figure *P*; they were obtained from test pieces 2 in. wide and $\frac{1}{4}$ in. thick with a $\frac{1}{4}$ in. dia. hole at the mid-point of the test length. The pre-loads applied were equal to 80% of the proof stress. Pre-loading has the effect of moving the R/M curve to the right as though the induced compressive mean stress offsets the tensile mean stress. With fully-heat-treated material ($\frac{\text{proof stress}}{\text{U.T.S.}}$ ratio of 0·9), this is also equivalent to increasing the stress range at all of the three mean stresses used (Fig. *P*). On the other hand, with naturally-aged material ($\frac{\text{proof stress}}{\text{U.T.S.}}$ ratio of 0·7) the shift of the R/M curve is equivalent to an increase in stress range at mean stresses of O and 6 tons/sq.in. only. At 12 tons/sq.in., there is no increase in fatigue strength due to pre-loading. The R/M curve for notched test pieces that were not pre-stressed has a kink in it and the curve becomes almost horizontal after about 6 tons/sq.in. due to local yielding round the notch, and it is therefore not surprising that by shifting the R/M curve to the right, there is no increase in the range of stress. It is possible that at a higher mean stress than 12 tons/sq.in., similar results can be obtained with the fully-heat-treated material. Thus an improvement due to pre-loading depends not only on the magnitude of the induced compressive stresses but also on the proof stress, the mean stress, and the applied stress range.

Mr. E. M. Lewis (W. S. Atkins and Partners): While Goodman and other fatigue diagrams are a very convenient way for research workers to present a lot of information in condensed form, designers would perhaps understand their work better if the results were presented in terms of the dominant variables, namely, a stress range superimposed on a quiescent stress and the number of cycles. The quiescent stress would normally be the sum of the stress due to static or dead loads plus any local or general locked-in stresses.

Some remarks in the discussion seem to suggest that a fatigue crack is the end of the world! I must support Dr. Whitman on this; we should regard fatigue cracking as something akin to corrosion and should deal with it by maintenance. When the time comes to scrap the structure it should be worn out fatiguewise as well as in other respects; not free of fatigue and capable of carrying on for many years.

Turning to Dr. Whitman's paper and referring to Fig. 8, it would seem that the method of plotting the 'programmed panels' results might be misleading—indeed, with their position in the top right-hand corner of the diagram they looked optimistic! Surely it would be better not to plot results for maximum applied stress against total cycles including other stress ranges on the same piece of paper as unprogrammed tests of applied stress against cycles.

Further to the programmed tests, I would enquire whether Dr. Whitman and Dr. Alder have plans for including corrosion as a variable in future tests?

Dr. Alder: Has Mr. Lewis any suggestions on how we should have plotted the results of our programme tests? More seriously, we plotted them in this way because we feel that they are representative of results obtained from the programme which we specify in Figs. 6 and 7. This does not have one high load but accords with a mathematical distribution, which should appeal to Mr. Lewis. We hope in due course to try other programmes, so as to get a general band of results in the top right-hand corner with an established lower level. In this way an easy comparison can be made with constant load level test results.

In the tables we have also given the summations of n/N, which give some measure of how our results are comparing with the linear damage hypothesis. With regard to the corrosion aspect, we know that the behaviour of the Bailey Bridge has been satisfactory in service for over ten years under civilian traffic. We therefore have a service yardstick with which to compare our programme tests, and if we can produce tests giving the same kind of answer I feel we would have achieved a reasonable correlation.

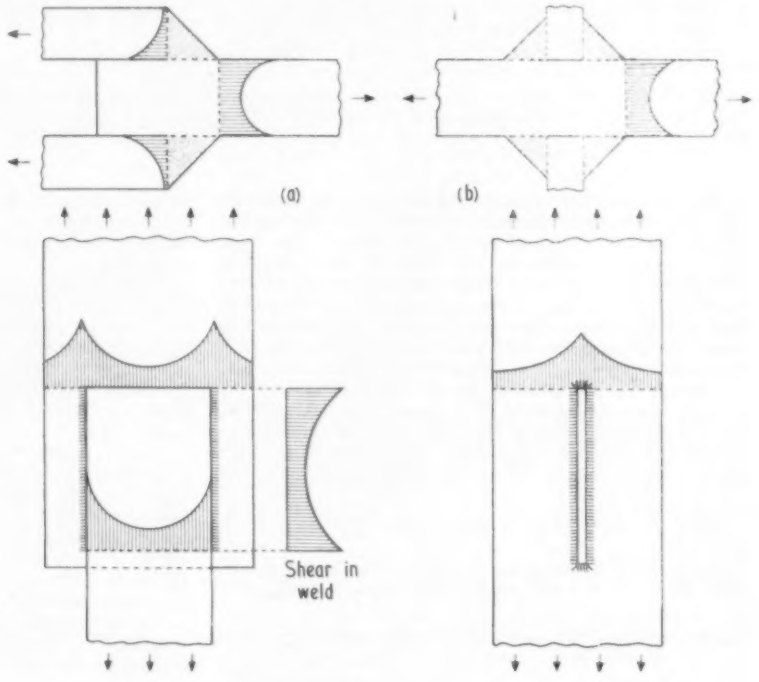
Session IV

The Fatigue Strength of Fillet Welded Joints in Steel
By T. R. Gurney

A Systemization of the Fatigue Strength Values of Mild Steel Welds *By A. Neumann*

(Chairman: Professor W. H. Munse)

Mr. Gurney (B.W.R.A.) in introducing his paper, stated that it was convenient to divide fillet welded joints into four main types: longitudinal and transverse, and load-carrying and non-load-carrying welds. Figure *R* shows qualitatively the stress distributions associated with each of the four types, the main differences being that transverse welds introduce stress variations through the plate thickness, whilst longitudinal welds affect the stress distribution over the plate width, and that load-carrying welds produce greater stress concentrations than non-load-carrying welds. From these diagrams it is obvious that, in general, transverse welds produce failure from the toe of the weld, whereas longitudinal welds result in failure from the end of the weld. He emphasized in particular the much lower fatigue strength of fillet welds in comparison with butt welds and the fact that load-carrying welds were worse than non-load-carrying.



R—Stress distributions in fillet welds:
(a) *Load-carrying welds;*
(b) *non-load-carrying welds*

Mr. Neumann (Z.I.S. Halle) explained that in developing his theory of fatigue strength, Stussi assumed that, for notched specimens, a linear relationship existed between K_f and mean stress, even though this could not be proved in all cases. Then for various notches it was possible to calculate theoretical fatigue strength curves (Figs. 5, 6, 7) and these have been compared with test results on welded specimens. Hence it was possible to define particular curves as relating to particular types of joint, all the fatigue strengths relating to 2×10^6 cycles, and the proposed specification has been set out in Figs. 12–19.

Mr. P. S. A. Berridge (British Railways; Western Region): Firstly, I would just like to ask Mr. Neumann whether his tons are 2000 lb or 2240 lb.

In his paper Mr. Gurney states very emphatically that the permissible stresses given in BS.153 are too high—I am thinking particularly of flange-to-web fillet welds in plate girders. Since most of the country is now making plate girders to BS.153 can someone give the new permissible stresses as soon as possible; I think it is up to B.W.R.A. to help in that.

Yesterday Mr. Gurney mentioned that he had obtained some encouraging results with girders in which these welds were made automatically. I take it that the type *D* specimen shown in Fig. 1 represents this type of connection, even though in this specimen the weld is only of short length.

[At this point Mr. Berridge showed some slides of plate girders during fabrication and macrosections of various web-to-flange connections. He stated that he very much preferred that these welds should have full penetration and that they should have a concave surface. He noted that Mr. Gurney had stated the day before that even the slightest amount of undercut would produce a reduction in fatigue strength, but he doubted whether it was possible to avoid this if these fillet welds were made with the web placed vertically. If the welds were made in the gravity position with the girders tilted undercutting could be avoided, and he always insisted on this being done.

He emphasized the value of using automatic welding to eliminate the imperfections which often crept into manual welding due to the tiredness of the welder, and he thought that the use of automatic welds for web-to-flange connections would avoid trouble where the fillet welds crossed the flange butt welds, because the high power would fuse it completely. Consequently he had done away with the use of cope holes and, particularly in view of Professor Munse's results, he thought he was right in so doing.

One slide showed a macrosection of a submerged-arc fillet weld which contained piping. He thought that the

open-arc process was better than the submerged-arc because a conscientious operator could see what was going on during welding. He had written to B.W.R.A. for advice and said that he had been told that submerged-arc welding was more prone to imperfections and that submerged-arc welds gave lower fatigue strengths. For that reason British Railways, Western Region used open-arc welding. He asked what difference there was in the results obtained by the two processes.]

Mr. Neumann: The conversion is to British tons.

Mr. Gurney: In this paper I have not considered continuous longitudinal welds at all. Specimen *D* in Fig. 1 merely represents an attachment, such as a bracket, and would be expected to fail from the weld end. If you have a continuous longitudinal weld you should not have a weld end, although with manual welding one may be present where two adjacent runs come together. This would not give such a low fatigue strength as specimen *D* because the stress concentration effect would be less, but it would isolate the point of failure.

With regard to your comment about undercut adjacent to longitudinal web-to-flange fillets, I do not think this is particularly critical. In this case the undercut is parallel to the direction of stress. Yesterday I was referring to the attachment of transverse stiffeners, in which case undercut along the toe of the weld is perpendicular to the direction of applied stress, and this is a much more dangerous state.

On the possibility of open-arc and submerged arc welds giving different fatigue strengths, it is certainly something of which I am not aware.

Dr. R. Weck (B.W.R.A.): I am surprised at Mr. Berridge's letter in favour of one process rather than another. This is the sort of thing we never do on principle. However, I do have a vague recollection about some correspondence and since I cannot remember having talked to the officer who wrote the letter to you, I do not think that we have said exactly what you claim we have said.*

In the particular case you quote, I do not think that undercut would be very important anyway because you have no transverse stress. What would be more important in this case is the evenness of the edge of the weld, and the absence or presence of weld ripples. So from that point of view I do not think one could decide in favour of one or the other process.

As regards this piping, you can get this as easily in submerged-arc welding as in open-arc welding. It is difficult to say why it happens. It may be due to rust or scale adhering to the plates or possibly to moisture in the powder. There is no reason at all for submerged-arc welding necessarily to produce piping. Mr. Dixon has a great deal of experience and perhaps he would say something about it.

I want also to refer to the second point raised. That is the demand that B.W.R.A. should provide these design data. You will realise, of course, that this is a very big job. To determine one point on one of Mr. Neumann's curves, for instance, you have got to carry out perhaps a dozen tests and this costs money. So far, in this country, no-one has been prepared to put up the money for this kind of thing. There are in the structural steel industry only about half a dozen contractors who build bridges. The others are not vitally interested in producing design data for bridges. The Government—that is D.S.I.R.—take the view that, if industry needs information they ought to get it and pay for it. The Railways themselves, who have fatigue laboratories in Derby, would well be in a position to get this data for themselves without relying on B.W.R.A. if they really thought it was urgently required. As far as we are concerned we can do no more than industry is willing to pay for.

Mr. R. P. Newman (B.W.R.A.): The beam tests to which we have been referring in these discussions are being carried out on specimens made by the submerged-arc process, and, as I said before, the results are looking very promising indeed. The question of undercut has, I think, been adequately cleared up in relation to the behaviour of the girder under primary bending. There may be some point in considering undercut at the top flange where one might have the possibility of transverse loading of the flange as in a gantry girder. With regard to cope holes, I think Mr. Berridge was fairly firm in his views yesterday about making flange and web butts before marrying up the components. Under these conditions, of course, the need for a cope hole does not arise. But if the flanges are attached to the web before splices are made, I think I agree with Mr. Gurney that there may be a case for considering whether a poorly made splice will not be worse than a cope hole, which gives the welder a better chance of making a sound butt weld in the flange.

If I sense the general feeling of the discussion on plate girders, it seems to me that B.W.R.A. is being challenged to produce a specification for a plate girder that would be regarded as Class A1 at Lloyd's. I think we could formulate a specification for a top-class plate girder and I think we should encourage industry to give us the necessary backing to prove our ideas, not only on the relatively small scale now available to us, but also perhaps on something approaching full scale. This is adopting the philosophy put forward by Mr. Lewis in his paper; namely that one should check the actual construction under a good approximation to service loading conditions.

My specification for this Class A1 girder would be for the automatic welding of the web-to-flange joints; and this means the stiffeners going in afterwards. I fully agree with Mr. Berridge on this. I would like to see full penetration welds through the web, particularly where it is necessary to take account of transverse loading of the flange in crane gantries.

Now what about stiffeners, which we have got to have? I think I am correct in saying that in Professor Munse's tests, whether the failures are in the pure moment or shear areas, they always occur from the ends of welds. So let us complete our specification by requiring continuous web-to-stiffener welds and longitudinal stiffener-to-flange welds and let us use spot heating to take care of the weld ends. I would suggest that these ideas are worth looking into and that the amount of work we are at present able to do, which I might tell you is about the equivalent of using the capacity of one-third of a testing machine, really should be increased sufficiently to enable us to prove them.

Mr. O. A. Kerensky (Freeman, Fox and Partners): The challenge has been made to the B.S.I. to provide a new specification or revise our old one. First of all may I say that in 1954, when the Fatigue Panel under the Chairmanship of Dr. Weck produced our present fatigue rules, there were no experimental results available for British steels, so the Panel's guesses must be considered as remarkably good. I have compared the British Standard specification with Mr. Neumann's curves and the agreement for mild steel is quite remarkable. We have no data for high-tensile steel of course.

As Chairman of the Standing Panel on the Revision of British Standards, I am sure that the Panel would be willing

* Mr. Berridge has since acknowledged that the correspondence did not refer to fatigue properties. With regard to imperfections, it was stated that porosity was occasionally encountered in submerged-arc fillet or partial penetration welds, and that this could be due to several factors, *e.g.*, entrapment of moisture, damp flux, the presence of rust, mill scale or other contaminents of which the submerged-arc process was less tolerant than the open-arc process. It was also stated that with heavy submerged-arc deposits, weld-metal impact values would be lower than those obtained from open-arc welds. Finally, it was pointed out that there were no grounds for excluding the submerged-arc process, provided that it was properly applied.

to undertake a revision, as soon as reliable data are available. In fact we were pressing for it and three committees are in existence in England today trying to solve this problem. These committees met a number of times and always landed on the same rock—no money! We could discuss in committee what we thought we should do, but the proofs were not forthcoming until B.W.R.A. did their recent tests. Dealing with the possible revisions of the British Standard, in the light of these papers, it would appear that we must introduce some rule to take account of the spectrum of loading to enable the designer (and particularly in the case of railway bridges he very often has the necessary data) to take account of the respective numbers of cycles of each applied load in arriving at his coefficient. And, secondly, we must quite obviously introduce more differentiation between various weld details so that we would have at least 3 different coefficients roughly along the lines suggested by Mr. Neumann.

The third point is this: I am not quite clear whether welds themselves have to be penalized. Mr. Neumann, in curve 19, produces stresses for fillet welds which are very low. Our present rules do not penalize the weld at all. I would like some guidance on this, and if the welds are not to be penalized, what are the optimum sizes of fillet welds?

Mr. Gurney has brought out the problem of load-carrying and non-load-carrying welds. We do not have that distinction now. I think it would be quite easy to introduce it, provided the research workers are satisfied what the different coefficients should be.

Spot heating has been suggested as a practical means of improving the behaviour of weld ends. Whilst I have no doubt that it can be done, I am very doubtful whether it is a practical proposition in the fabricating industry as it stands today. I think we could spot heat, but I am not sure what supervision would be necessary to ensure its effectiveness. If the spot heating were not done correctly, you might do more harm than good.

I think the most interesting feature that has transpired from the two papers is, if I read it correctly, that Mr. Neumann has verified Stüssi's theory by exhaustive tests and he showed us yesterday that his results agreed remarkably well with the American ones. If that is so, then at least part of our desperate cry for design rules has been answered, if I may say so, from behind the Iron Curtain. The rules given here, if they pass our own critical examination, give us all the answers we need. In particular, they answer the question which I posed yesterday about the use of high-tensile steel under high mean stress conditions, and invariably they allow you a 50% increase in permissible stresses. The only snag is that all these results are for St 52 steel, and British steel may not be as good, but I am sure the British steel industry could eradicate any faults there may be in BS.968 steel for use in structures subjected to fatigue loading. I do not think that steels ND.1, 2, and 3 are any use at all as they are only mild steels. It would be better to produce high-tensile steels with good fatigue properties and notch ductile characteristics, and I would remind you that most of our high-tensile steels are, in fact, better than mild steel from this point of view. In fact, if you have got to pay an extra £10 or £20 per ton you might as well be allowed to use higher stresses as well.

Mr. Gurney: I agree that it would be very nice to have a rule which enabled one to take account of the load spectrum applied to a structure but, as we have already heard, research on this subject, at least as far as welded steel structures are concerned, has only just started and it is very difficult to produce a rule from only about 6 test results. However, it is certainly something to which we must pay attention in the future. I also agree that we must have more differentiation between weld-types—for example between load-carrying and non-load-carrying joints.

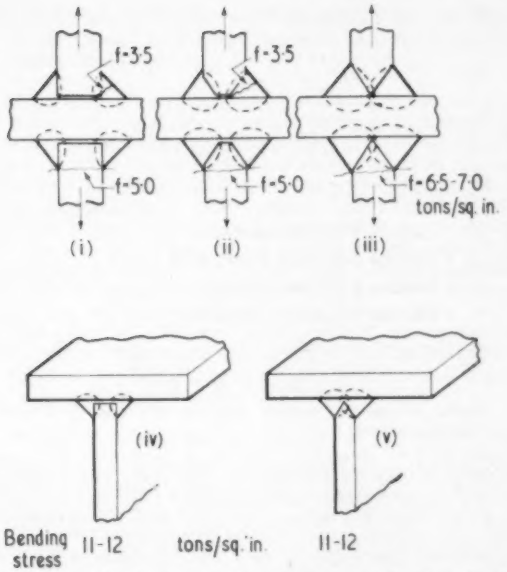
On the question of design stresses for the welds themselves I would like to refer Mr. Kerensky to Fig. 4 in my paper where I have plotted a few test results. Many of these were obtained by accident, *i.e.*, they just happened in the course of other experiments—but Wilson's results were intended. He took great care over the results plotted in the scatter band to ensure that he did not get initially cracked welds and he inserted soft iron wires between the plates being welded to give some elasticity during welding. A truer result would probably be that labelled "Wilson's welds initially cracked". One thing we have found in our tests is that if you have a weld crater containing even a very slight defect coinciding with the end of a longitudinal weld then it may initiate fatigue cracking. On the other hand you must remember that at the end of a longitudinal load-carrying weld there is quite a severe stress concentration, so these results may not be strictly comparable with the case of web-to-flange fillet welds where this extra stress concentration effect is absent. I think our present rules are perfectly adequate for that case and for non-load-carrying welds, but it might be worth thinking again about the discontinuous load-carrying weld, which occurs for example at the panel points of lattice girders.

With regard to spot heating, I think it would be quite easy to apply, but I would be the first to agree that we need some means of inspection. I think there are paints on the market which might provide the answer to this; they would provide a means of showing what temperature had been reached; and they would show where spot heating had been applied. Local compression, of course, does not suffer from this difficulty. You can measure the indentation and this is quite adequate for ensuring that treatment has been correctly carried out. I disagree entirely with the suggestion that you may do more harm than good by spot heating. You can only treat a longitudinal weld and longitudinal welds are already up to yield point stress. Therefore, even if you treat in the wrong place, you cannot produce a worse fatigue strength. On the other hand it is a different matter if a designer increases his stresses because he has spot heated. In this case, if the heated spot is in the wrong place, he may well be in danger. It is a question of purpose in applying spot heating. Are you going to prevent cracks using present design stresses, or are you going to use spot heating as a reason for increasing your stresses. In one case it could be dangerous and in the other it could not.

On the question of the comparison between the German results for St 52 and our own BS.968, I think that all the information that has been produced in this Symposium so far has shown that there is no benefit to be gained by using a high-tensile steel at 2,000,000 cycles or at low values of mean stress. On the other hand, I think there is a very good case for using higher stresses for small numbers of cycles and/or high mean stress.

Mr. Neumann: I would like to add some further information in relation to Mr. Gurney's paper. I have obtained the following results using the specimens shown in Fig. *S*, the tests being carried out under pulsating tension loading. The fatigue strengths quoted refer to 2×10^6 cycles. Specimens of type (i) gave a fatigue strength of $3\frac{1}{2}$ tons/sq.in. on the weld throat, or 5 tons/sq.in. for failure through the plate at the toe of the weld. No benefit was obtained by decreasing the lack of weld penetration even to 1mm, as indicated by type (ii), but the strength was increased to 6·5–7·0 tons/sq.in. if complete penetration was obtained (type (iii)), and failure then occurred through the plate at the weld toe. These results refer both to manual and submerged-arc welding. In the case of beams in bending no difference in strength was obtained between types (iv) and (v), the strength being 11–12 tons/sq.in. for both manual and submerged-arc welding, but the submerged-arc welds showed a greater sensitivity to porosity.

Mr. Kerensky: With regard to Mr. Gurney's comments I did mean that more harm than good would be done if we



S—Results of pulsating tension tests on steel St 37 at 2×10^6 cycles, $f_{min}/f_{max}=0$

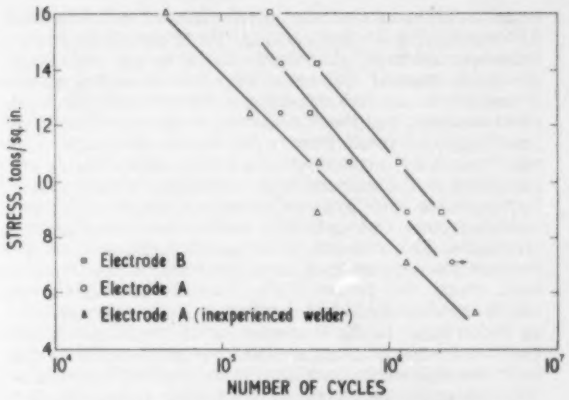
took advantage of spot heating and used more optimistic stresses. As to his remark that he finds St 52 no better than mild steel, this is certainly contradicted by Mr. Neumann's work, and that is the question I am asking. On all his curves of allowable stresses he has shown a 50% increase for high-tensile steel in the high mean stress region.

Mr. Gurney: I agree with most of the improvements in strength for high-tensile steel recorded by Mr. Neumann in his Figs. 12–19, certainly in respect of those at high mean stress. All these, of course, refer to 2×10^6 cycles, but I would also like to suggest that there is a good case for increasing stresses for smaller numbers of cycles over the whole range of mean stresses.

Dr. Weck: I think it is now time that this should be brought out into the open. Some time ago we were rather startled by the fact that very much higher permissible stresses were allowed in West Germany for St 52 than we would allow for BS.968, and if you look into Mr. Gurney's paper on page 184 in the last paragraph before "Residual Stresses" you will find a very tactful reference there to some work we have carried out on St 52 plate obtained from Germany. We found that this particular plate gave no better results under fatigue conditions than mild steel. It was in the same category as our own high-tensile steels. We raised this matter in Commission XIII of the I.I.W. and we found—and the Netherlands delegate, who is also here, confirmed it—that St 52 did not give better results than mild steel. If you look in Mr. Neumann's paper you will find that the curves he draws, on which there are experimental points, are all curves obtained for St 37. The curves for St 52 show no experimental points at all and I wonder why they have been omitted.

Mr. Neumann: The data are available in a book we have just published, and the graphs in the paper are summaries.

Professor Munse: I believe we may all be talking about the same general picture, Mr. Kerensky. In our discussions yesterday, when we were talking about alternating and pulsating tension stresses we decided that there was very little difference between these materials. When we get to high mean stress conditions (towards the right-hand side of Mr. Neumann's plots) we do find that there is a difference



T—Results of repeated tension test son mild steel fillet welds

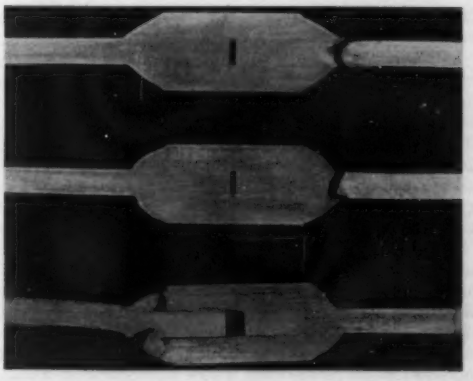
in the behaviour of the steels and this may be the place in which the higher strength steels will show advantage.

Dr. G. F. Modlen (Sheffield University): These remarks deal mainly with the effect of weld profile on the fatigue strength of load-carrying fillet welds.

At Sheffield University, Mr. Baxter and I have been working on the fatigue of fillet welds, using a specimen similar to Fig. 2*g* of Gurney's paper. The specimens were of $\frac{3}{8}$ in. mild steel plate, the cover-plates being 2 in. long. Plates approximately 9 in. wide were welded up, and test pieces $1\frac{1}{2}$ in. wide were cut from the plate for fatigue testing. Each weld was made in two runs, using first a 10 and then an 8 s.w.g. electrode. Two types of electrode were used: Electrode *B* was chosen because the manufacturers claimed that it deposited a weld of concave profile. Fatigue testing was in repeated tension, from a constant small value to the maximum. In the S/N curves it is the stress range which is shown.

A comparison of the S/N curves (Fig. *T*) with the photographs of the fractured specimens (Fig. *U*) shows that the welds that appear to have the most favourable shape do, in fact exhibit the best fatigue properties. The welds deposited by the inexperienced welder were badly undercut: nevertheless, because of the short leg length, the fatigue crack started at the root of the weld and propagated through the weld metal.

The width of the test pieces used, namely, $1\frac{1}{2}$ in., was chosen so that the loads required to fracture the specimens should lie conveniently in the range of the machine. Specimens of different widths have been prepared and



U—Typical fractures: (a) *Electrode B;* (b) *electrode A;* (c) *electrode A, inexperienced welder*

tested in different machines, and it can be seen from the S/N curves (Fig. *V*) that although the slopes of the curves have been markedly altered, the 2×10^6 fatigue strength is not much changed. The use of very thin specimens makes it possible to cut out simulated welds conveniently from sheet material, and the S/N curves obtained indicate that benefits would result from a decrease in the angle θ at which the weld metal meets the parent plate. This is not consistent with Duchinskii's or with Bykov's work, but it is compatible with Solakian's data[8] on the stress concentration factors for such fillet welds determined photoelastically. The absolute value reported depends on the detailed geometry at the base of the notch where the weld bead meets the parent plate. Nevertheless, Solakian's results do show a marked decrease in stress concentration as θ decreases. In the simulated welds it was also found that, for $\theta = 51°$, cracking started from the root of the weld, as in the real welds made by the inexperienced operator. The change in the mode of fracture is similar to that brought out by Mr. Gurney in the discussion of Professor Stallmeyer and Munse's paper on welds in high-strength steels. I would like to ask Professor Munse where his full penetration T-fillet welds failed—presumably it was at the toe of the weld. The results of the fatigue tests are summarized as follows:

Width of Test Pieces in.	*Electrode*	*Stress Range for 2×10^6 cycles tons/sq.in. (Repeated Tension)*	*Remarks*
1·5	A	6·0	Poor welds
1·5	A	7·2	
1·5	B	9·0	
0·2 and 0·050	A	approx. 8	
0·2 and 0·050	B	9	

I would like to thank the Inspector of Naval Ordinance and Superintending Scientist, Sheffield; Sheffield College of Technology and the Department of Metallurgy, Cambridge University, for making testing factilities available.

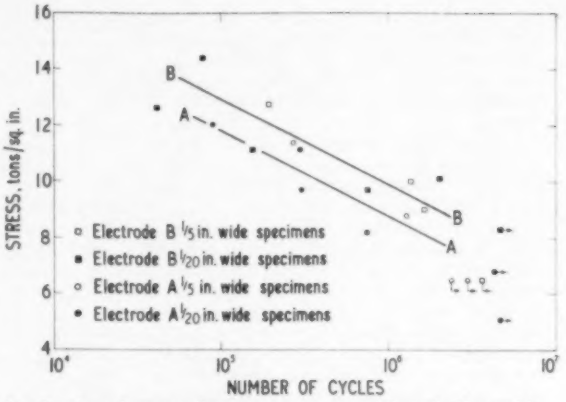
Professor Munse: In reply to the last question, the T-fillets failed in the weld, the failure initiating at the root. When there was a full penetration weld the failure generally occurred at the toe of the weld in the main plate material and not in the weld itself, so you have a different type of failure in these two cases.

Mr. Gurney: I am delighted to find that Dr. Modlen has managed to prove what one would expect. Nobody else has yet done so. One possible reason for Duchinskii's result (this is pure guess-work because he does not say anything about it), is that he may have had undercut in both cases. If you consider how these welds were machined to get them triangular, it must have been transverse to the specimen. This may be the answer.

Dr. J. G. Whitman (M.E.X.E.): There are three points I would like to mention as briefly as possible:

Firstly, in connection with one of the specimens (type *G*) mentioned in Mr. Gurney's paper, we have had some experience which might be of interest. We obtained the normal type of fatigue failure at the toe of the weld under pulsating tension, but when we used alternating loading failure occurred through the weld throat. This puzzled us until we thought of the secondary stress which might cause the cover plates to develop transverse deflections, and on taking measurements we found that this movement was, in fact, taking place. Our next step was to put a bolt through the cover plates and tighten it up lightly and this reproduced the original type of fracture at the weld toe with higher fatigue stresses. I think this is a point to be watched with this type of specimen.

My second point concerns the control of spot heating which has been mentioned. I am wondering if it has occurred to those present to use induction heating for this process. We have been concerned with this form of heating



V—Results of repeated tension tests on mild steel fillet welds (wide specimens)

for another purpose entirely but I fail to see why it cannot be used for spot heating with complete control. I visualize a torch type of instrument which you push up against the job with a control box behind on which you adjust settings for different thicknesses so as to give the diameter and the temperature of spot which is required.

Thirdly, we have been talking about the use of residual stress for the increase of fatigue strengths and yet in most welded structures there are already compressive residual stresses present. Why cannot we make use of these. Take as an example an I girder made from three plates with longitudinal fillet welds. Due to welding it shortens in length by quite a considerable amount, and if you calculate the mean stress to cause that shortening you find quite high values result, which are obviously composed of tension stresses around the fillet welds balanced by compressive stress in the remainder of the structure. If we can identify these areas, surely these would be good places to weld our stiffeners and thus make use of the residual stresses already present.

Mr. Gurney: I am glad to hear of the idea of induction heating. It hasn't particularly occurred to us and it might be very useful. On the second rather nice idea, unfortunately I think Dr. Whitman has forgotten that the other welds he puts down to attach the stiffeners will produce residual tensile stresses and it is those that will cause trouble.

Mr. A. G. Senior (W. S. Atkins and Partners): I would like to make two points in connection with Mr. Gurney's paper, both on the aspect of spot heating. A previous speaker has suggested an alternative way of introducing metered quantities of heat using induction heating. I would suggest that there is already available a well-developed method of doing this and that is the technique of stud welding where equipment of this type has been used for some forty years. The process would obviously require some development for spot heating, but it does have the big advantage that it leaves a visible means whereby the inspector can see that the job has been done—either by leaving behind a short stud or button, or, if a non-consumable electrode is used, by leaving a visible mark or indentation in the plate.

The other point I would like to make concerns the suggestion Mr. Gurney made a little earlier that it is impossible to make matters worse by applying spot heating in the wrong places. I think what he meant here was that if you already have locked in tensile stress at yield at your weld notch detail, then spot heating in the wrong place cannot make matters worse; but I would suggest that it may be possible by spot heating to increase the residual stresses in notches which are not associated with welding

but which are associated with changes of section, bolt-holes, or things of that sort. I would like Mr. Gurney's comment on that please.

Mr. Gurney: I was, of course, speaking in the context of welded structures. However it is perfectly true that you may do damage in the circumstance mentioned by Mr. Senior and in fact I think Trufyakov has shown that you can reduce the fatigue strength due to a hole by doing just this.

On the question of stud welding, I have heard of this proposal before. It is certainly a possibility, but I do not like the idea of leaving a stud because it forms an extra stress concentration. We have used spot welding machines but they also have their dangers. You can overheat very easily and we have produced some failures from overheated spots. We produced a weld 'nugget' in the middle of the plate. This usually has porosity and can also leave a rather severe notch on the surface, and you can either fail through this weld nugget or at the edge of it.

Mr. R. G. Braithwaite (Braithwaite & Co. (Engineers) Ltd.): When one uses automatic welding for making fillets, the degree of penetration can vary with the process and the procedure used. Increases of static strength are possible, therefore, depending upon the effective throat thickness produced. On the other hand there is sometimes a limitation here in that one can run into hot-cracking at the root if penetration is excessive and there would seem to be a need for an investigation of this point. With regard to the heat-spot technique, it might be possible to obtain the required residual stress system by depositing weld beads at strategic sites. I carried out some static tests of notched plate specimens and observed a rather better performance in terms of ductility when weld beads were placed on the surface in the correct position with regard to the notch.

Mr. Gurney: Unwittingly, Mr. Braithwaite has managed to put the clock back twenty-five years to American work where someone did try to use welds as a means of spot heating. The trouble with this is that under fatigue conditions you get failure from the end of the weld bead.

Mr. D. C. Dixon (The Cleveland Bridge & Engineering Co. Ltd.): Dr. Whitman's idea may not be so bad. There is a good deal of information on the quantity of residual stress you put into the flanges of a plate girder when you weld it up and there is also some information on the stress at the end of a stiffener when you have welded it on. We have it because we like our girders to end up with the right amount of camber and, by adjusting the heat input, we can get that camber without any great difficulty. We know how much the stiffener holds the flanges out when they try to come in so there is information available on the amount of residual stress you leave in.

I thought I had better say a bit about open-arc and submerged-arc welding. The great benefit of open-arc welding is that you can weld over water, rust, millscale or anything else you have and it gives you a great deal of latitude, but with submerged-arc welding the plate has to be cleaned and you have to exercise more care. Ultimately, however, one does have more control over the shape and finish of the weld produced.

Mr. Gurney: I would like to know how Mr. Dixon got his residual stress. Measuring residual stresses is an extremely difficult process and I rather suspect that these are residual stresses going in the wrong direction.

Mr. Newman: I think Mr. Dixon has got his residual stresses from B.W.R.A. I am sorry to have to destroy the harmony of agreement between Mr. Neumann and everybody else, but we hope to get rather better than 12 tons/sq.in. on our beams in bending. Control of spot heating is a subject of interest obviously. Dr. Weck said that there are only about six firms making girders for bridges. Mr. Haas might put a couple of torches aboard his caravan! Professor Munse made the point that at high ratios of min/max stress, high-strength steels show to advantage. I am not altogether happy that there are experimental results which establish a difference in actual strength, but surely it would be quite logical to look at the problem in these terms. If one accepts that there is one line on the Goodman diagram representing allowable stresses for mild and high-tensile steels, then at the upper end one would have a higher cut-off point (the factor against yield) for high-tensile steel and such an extension should be permitted.

Finally, we very much welcome Dr. Modlen to the 'club'. His first results, 9 tons/sq.in. on a load-carrying fillet weld look very rosy indeed. May I ask him, however, to substantiate the 2,000,000 result and even more important the 10,000,000 result with a few more figures than he has been able to plot so far.

Dr. F. Koenigsberger (College of Science and Technology, Manchester) wrote: Mr. Gurney, in referring to the work published by Dr. Green and myself, expresses doubt as to whether the arrangement of the welds proportioned in relation to their distance from the neutral axis of the angle is the reason for the increase in fatigue strength. He seems to have overlooked the further work published in *British Welding Journal* in September 1955. We actually tested two types of 'proportioned' arrangements, one in which the gusset extended in front of the welds and the other in which it did not do so. Only the former resulted in a slight improvement in fatigue strength. We therefore concluded (page 371): "In the weld arrangements types 1 and 3, the welds at the toes of the angles finish at the ends of the gusset plates. This position is also one where peak bending stresses exist owing to the eccentric loading of the angle, and it follows that in these two cases the stress concentration due to the weld coincides with the peak bending stress. These two are separated in the case of specimens of type 2, and their higher fatigue resistance is attributed to this fact. These results show that the proportioning of the welds is no criterion for the strength of the joint, and that the result is only influenced by stress considerations." Hence I do not think we have left the doubt about which Mr. Gurney was worried, and we have proved that, for both static and fatigue loading conditions, the proportions in which the welds are arranged for connecting rolled angle sections to gusset plates does not influence the load-carrying capacity of the joint. This is only influenced by stress concentrations.

Mr. Gurney: I am grateful to Dr. Koenigsberger for drawing my attention to this other work, which I had indeed overlooked, and I am glad that the doubt has now been removed.

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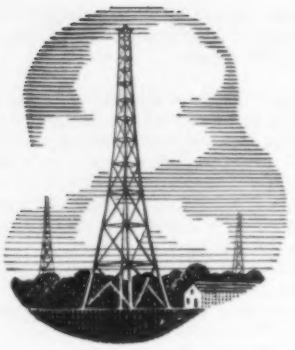


News of the Institute and Branches
B.W.R.A. · Other Societies ·
and Industry

A MESSAGE FROM THE RETIRING PRESIDENT

Dear Member,

5th July, 1960

From the short report of the Select Conference on Education, printed below, you will learn that we may hope shortly to see a beginning made in the expansion of the educational facilities for which we have been pressing. But it would be lamentable if when further Courses are available they are not immediately filled by students from Universities, Colleges, and Industry. I would now therefore suggest that the Institute in co-operation with the B.W.R.A. will need to foster and actively pursue a campaign to encourage Industry towards a realization that it needs engineers and metallurgists with a basic knowledge of the welding processes and their application, as well as trained welding specialists, both technicians and technologists.

I am happy to announce that, to give a lead in this direction, The British Oxygen Company Limited has offered two bursaries a year for seven years, if the Courses are started in the Autumn of 1961, to recipients selected by the Institute of Welding for post-graduate Courses at a suitable College or University designated by the Ministry of Education as the centre for advanced studies in welding technology. Furthermore, the Group will start the Courses by sending one or more members of its staff to these in the first year. This is a splendid gesture which the Council at its meeting next week will no doubt accept with grateful thanks. May I express the hope that after such a fine example other industrialists will feel constrained to support and encourage the use of the facilities which now seem within sight.

An industrialist has to give much thought to planning for capital investment and ensuring a profitable return on money invested in buildings, plant and equipment. But the same careful thought is not always given to capital investment in brains. In the field of welding I am sure that capital investment in trained technologists and technicians would not only provide a generous 'return' on money invested but also it would help to keep British engineering to the fore in the increasingly competitive future which we face. Engineering cannot live without welding and without welding well it cannot live well.

We have now reached a point at which every Member can lend a hand, and I hope we shall all lose no opportunity of talking about these important things to all Industrialists with whom we come in contact. I know that our new President, Mr. Fuchs, will continue to give a lead to what I regard as the second half of the problem which confronted us twelve months ago and in this I am sure he will have the active support of every Member.

As I have said this is a matter of national and industrial importance but it is also important to the future of our Institute. More education in welding at all levels is bound to raise the status of welding specialists and increase the influence and prestige of the Institute of Welding of which we are all members. So you will lend a hand by getting people talking about it—won't you?

With all good wishes,

Yours sincerely
E. SEYMOUR-SEMPER
(*President 1959–60*)

Select Conference on Advanced Education in Welding

Early this year the Committee on Educational Policy set up by the President decided to hold a Select Conference on Advanced Education in Welding. This was held at the Institute on the 21st June last and nearly fifty prominent Educationists and Industrialists accepted the President's invitation. Among the educational bodies represented were the Ministry of Education, the Department of Scientific and Industrial Research, the National Council for Technological Awards, the senior engineering institutions, the engineering or metallurgy departments of the Universities of Bristol, Cambridge, London, Manchester and Wales, and technical colleges at Birmingham, Sheffield, Sunderland and Wandsworth. On the side of industry were representatives of the Federation of British Industries, the Aluminium Development Association, the Tank and Industrial Plant Association, and directors or representatives of management from Associated Electrical Industries (Manchester) Ltd., the British

Transport Commission, Central Electricity Generating Board, Edwin Danks & Co. (Oldbury) Ltd., the English Electric Co. Ltd., Fairfield Shipbuilding and Engineering Co. Ltd., Imperial Chemical Industries Ltd., Quasi-Arc Ltd., Tube Investments Technological Centre, and Whessoe Ltd.

Mr. Seymour-Semper, from the Chair, welcomed the members of the Conference, explaining that it had been called because of the increasing concern felt by the Institute and the British Welding Research Association at the shortage of welding technologists in Britain and the difficulties which the British engineering industry was likely to experience as a result, in applying modern welding techniques to production.

Four short addresses followed. Dr. Nicol Gross spoke on "Industry's Need of Qualified Welding Technologists"; Mr. G. Parsloe on "Welding Education in the United Kingdom and Abroad"; and Dr. R. Weck on "The Content and Scope of a Course of Study for Welding Technologists". Then H.M.I. Mr. F. Caunce, in a paper entitled "Advanced Education in Welding Technology—Contribution by the Ministry of Education", announced the intention of the Ministry to use their influence towards securing a better coverage of welding in existing courses and to explore the possibility of setting up full-time courses in advanced welding technology.

It is hoped to publish the addresses and a report of the ensuing discussion in the Journal. There was substantial agreement among the educationists with both the proposals of the Ministry and also that the principal obstacle met by advanced courses offered at Cambridge and in the past at Manchester College of Technology had been the reluctance of employers to release qualified men for courses which could not be shorter than a year, if they were to achieve their object.

Those industrialists who spoke, while admitting the need for better education in welding, mostly emphasized the difficulty of releasing graduate engineers and metallurgists for a year's course and urged the Institute to continue its study of the problem, in the hope that a solution less inconvenient to industry would emerge.

The Conference did not pass any formal resolution but it approved generally the President's summing up of the discussion which looked forward to:

(i) The introduction of a post-graduate Course in Welding Technology
(ii) The need to make welding an integral part of the instruction given in engineering courses at Universities and Technical Colleges
(iii) The encouragement of and co-operation with Technical Colleges to provide welding education at technical level for technicians engaged in the design and fabrication of welded components.

INSTITUTE ACTIVITIES

Council for 1960-61

The Council election results announced at the Annual General Meeting of the Institute held on 14th July were as follows:

Elected unopposed
President
Mr. E. Fuchs, M.A., A.M.I.Mech.E.
Vice-President
Mr. H. West, M.Sc., M.I.Mech.E., M.I.E.E.
Honorary Treasurer
Mr. W. E. Harriss
Representative of Companions
J. Hooper
Representative of Associates
A. Evitts

The following were elected to represent the classes named in the ballot:

Industrial Corporate Members
C. Humphrey Davey, J. A. McWilliam,
Fellows, Members and Associate Members
G. M. Boyd, O.B.E., F. Clark, M.B.E.
J. A. Dorrat, R. J. Fowler

The President, 1960–61

Edgar Fuchs, M.A., A.M.I.Mech.E., on leaving the Manchester Grammar School, studied mathematics and engineering at Cambridge University. After two years' practical training at Mather & Platt Ltd. he worked with that firm as centrifugal pump designer, and became an Associate Member of the Institution of Mechanical Engineers. Since 1928 he has been with Imperial Chemical Industries Ltd., Alkali Division, at Northwich, first as manager of the then newly-formed Instrument Department and later in charge of power generating plant and other major running machinery. In 1936 he was appointed Boiler and Structural Shop manager with welding as his particular field, pioneering work on all-welded pipelines and structures being his most important tasks. During the war the results of this work were applied to pipelines in a number of factories and to the fabrication of large pontoon sections for Mulberry Harbour and many welded buildings.

In 1945 Mr. Fuchs joined the Engineering Department as full-time Welding Engineer, with responsibility for weld quality in its widest sense. In this capacity he has served on many committees of the Institute, the B.W.R.A., B.S.I. and I.I.W., has been part author and editor of the I.C.I. Welding Handbook, published in 1951 as "Welding Practice", and has presented numerous papers to the Institute and its Branches.

Edgar Fuchs

Since 1955 Mr. Fuchs has been in charge of the I.C.I., Alkali Division, Materials of Construction Section, dealing with the application to chemical plant of metallic and non-metallic materials, welding developments, and corrosion prevention.

Relaxation from his professional activities are chamber music, gardening, and travels in the countryside and abroad.

Vice-President, 1960–61

H. West, M.Sc., M.I.Mech.E., M.I.E.E., has been Managing Director of Associated Electrical Industries (Manchester) Ltd. since last April. He joined Metropolitan-Vickers as an apprentice in 1918. Much of his early work was on motor development, and in 1940 he became Chief Engineer Motor and Welding Departments. In 1946 he became Chief Electrical Engineer, and was appointed to the Board in 1951.

In 1957 Mr. West ceased to be Chief Electrical Engineer, retaining his seat on the Board as Director of Electrical Engineering. This was to permit him to devote more time to the affairs of the AEI–John Thompson Nuclear Energy Company, of which he had been appointed Managing Director in 1956. Mr. West was associated with the AEI–John Thompson Nuclear Energy Group from its inception, and when this was formed into a Company he was the first Chairman of its Management Committee. He ceased to be a Director of Electrical Engineering when appointed Assistant Managing Director at Manchester in January 1960.

H. West

Mr. West is also a Member of the Board of Partners of The Nuclear Power Group, Director of Metropolitan-Vickers Electrical Co. Ltd., Metropolitan-Vickers-Beyer, Peacock Ltd., Sunvic Controls Ltd., Nucleonic Investments Ltd., Associated Insulation Products Ltd., Micanite & Insulators Co. Ltd., Chairman of Nuclear Graphite Ltd., Associated Electrical Industries–GRS Ltd., Metropolitan-Vickers Electrical Export Co. Ltd., Newton & Co. Ltd., Newton Victor Ltd.

He was Chairman of the North Western Section of the Institution of Electrical Engineers in 1953–4, and is a past member of Council.

Mr. West has travelled extensively in South Africa, the Middle East, Russia, Europe and North America.

Amendment of By-Law

At its Meeting of 9th June 1960 the Council amended By-Law 19 to read as follows:

"Subject to compliance with such conditions of admission as the Council may determine from time to time, a member of any class shall have the right to attend technical discussion meetings of the Institute whether organized by the Institute itself or under the auspices of any of the Branches, and, if the accommodation permits, to introduce not more than one guest."

Chairman of the Executive Committee

In June, Mr. R. E. G. Weddell completed the statutory term of three years as Chairman of the Executive Committee, which he undertook at the invitation of Sir Charles Lillicrap, President, in 1957. The Council has placed on record its appreciation of the devoted service which Mr. Weddell has rendered to the Institute over so many years, and particularly during his tenure of the Chair of the Executive Committee. At the same Council Meeting, Dr. N. Gross accepted appointment as Mr. Weddell's successor for the three years 1960–3.

Committees of the Institute

The new Council, meeting in July, decided on a number of changes in the Terms of Reference and composition of its Standing Committees.

The principal changes are the appointment of an Education Committee, with three Sub-Committees responsible for the Institute's examination, its co-operative work with Universities and Technical Colleges and the management of the School of Welding Technology, and a substantial reduction in the size of the Technical Committee, made possible by the substitution of groups of reporters for most of the sub-committees and panels concerned with special subjects.

The Council is most grateful to all members who have helped by service on standing committees and sub-committees, and believes that the reduction in size, which will, of course, reduce the Council's demands on members, will also improve the efficiency of the Institute's committee work.

Librarian

In the middle of July, Dr. Elsa McNeil Sinclair, who has been appointed Librarian with the Institute in succession to Miss Rosemary Urwin, took up her appointment. Dr. Sinclair holds the M.A. and Ph.D. degrees of Edinburgh University, and has studied also at five other Universities on the Continent.

Year Book and List of Members

Next November the Institute will publish a Year Book containing the names and addresses of all its members. This will be the first printed List of Members since the earliest days of the Institute. All Corporate Members will receive a free copy.

MEETINGS

Forthcoming Meetings

The **Autumn Meeting** of the Institute will be held in London from **1st–3rd November** next, opening with the President's Address on the evening of 1st November and closing with the Annual Dinner at the Park Lane Hotel on the evening of Thursday 3rd November. The theme of the Meeting will be The Metallurgy of Welding and Brazing.

The **Second Annual Lecture for Young People** will be given by Professor J. G. Ball at the Institute on the morning of Thursday **5th January 1961.**

The dates of the **Spring Meeting** of 1961, which will also be held in London, will be **24th–28th April**, which overlaps with the Engineering, Marine, Welding and Nuclear Power Exhibition at Olympia. The theme of the Meeting will be Recent Developments in Welding and Allied Processes.

The Netherlands Welding Society has invited members of the Institute to a Joint Meeting in Utrecht, coinciding with the Society's Welding Exhibition there, from Wednesday **31st May** to Friday **2nd June 1961**. The theme of this Meeting is to be Aluminium and its Alloys.

Spring Meeting, 1960

The Annual Spring Meeting of the Institute was held in Droitwich on 9th–11th May and, in regard to attendance especially, it was one of the most successful meetings that have been held.

A novel feature was a display of machines and products illustrating some of the newer welding processes and the various techniques of metal spraying. The following companies had stands in the Winter Gardens Hall, and provided technical staff to answer members' questions on the equipment displayed:

F. W. Berk & Co. Ltd., Schori Division
British Oxygen Gases Ltd.
Edwards High Vacuum Ltd.
The English Electric Co. Ltd.
Hancock & Co. (Engineers) Ltd.
Lincoln Electric Co. Ltd.
The Metal & Plastic Coatings Association
Metallisation Ltd.
Metallizing Equipment Co. Ltd.
Quasi-Arc Ltd.
Research & Control Instruments Ltd.
Rockweld Ltd.
Rubery Owen and Co. Ltd.
Wall Colmonoy (Canada) Ltd.

The meeting started with a reception at the Worcestershire Brine Baths Hotel, where members and guests were received by a Past-President of the Institute, Mr. R. G. Braithwaite.

There were three technical sessions in the Winter Gardens Hall, at which a series of papers on the newer welding and allied processes was presented and discussed. The first session, on Tuesday morning, 10th May, under the Chairmanship of Dr. R. A. Creswell, dealt with metal spraying and droplet transfer in arc welding. The second session on Wednesday morning, under the Chairmanship of Mr. I. H. Hogg, dealt with two new welding processes and fine wire welding. The final session, on the Wednesday afternoon, was devoted to electro-slag welding, and was presided over by Mr. E. Seymour-Semper.

During the technical sessions the Sir William J. Larke Medal for 1959 was awarded to C. A. Terry and E. A. Taylor for their paper "*Welding of Cupro-Nickel and Aluminium-Bronze Alloys*" (*B.W.J.* May 1956, p. 211). This is the second time that Mr. Taylor has received this award.

The afternoon of Tuesday, 10th May, was spent in interesting visits to the works of the Austin Motor Co. Ltd., Longbridge, John Thompson Ltd., Ettingshall, Thompson Bros., Bilston, and Dowty Mining Equipment Ltd., Tewkesbury. Reports of these visits are given below.

The Spring Meeting ended on the evening of Wednesday with a Dinner at the Raven Hotel, at which the Principal Guest was Councillor Robert Jolliffe, the Mayor of Droitwich. In proposing the toast of the Institute, the Mayor spoke of the facilities for meetings offered by his borough, which had a Royal Charter going back some 700 years. He sincerely hoped that the Institute would visit Droitwich another year.

In his response, the President of the Institute, Mr. E. Seymour-Semper, spoke of the valuable contributions being made by the Institute in the educational field but pointed out that much more needed to be done if Britain was to keep pace with other countries in producing qualified technologists.

The toast of the guests was given by Mr. J. F. Lancaster, Chairman of the Institute's Programme and Publications Committee. He welcomed the attendance of so many visitors connected with the metal spraying industry, and was pleased to know that they would be increasing the membership of the Institute.

Mr. C. A. Curson, Honorary Secretary of the Metal and Plastic Coatings Association, responded, and referred to the recent decision of his Association to co-operate more directly with the Institute—an action that would benefit greatly both bodies.

Works Visits

Austin Motor Works, Longridge—Approximately forty members spent an enjoyable and instructive afternoon at the Austin factory in Longridge. The tour started in the fabrication shop, where bodies and body sub-assemblies are made from pressings, using fusion- and spot-welding, from where members were taken through the degreasing, phosphating and priming shop, where whole car bodies twisted on horizontal spits in and out of vats containing degreasing fluids or paint.

The next stage inspected was the body assembly line, where the empty shells from the final paint shop were given doors, windows, lamps and seats, appearing to grow of their own volition as they were moved slowly along by the conveyor. Plucked from the end of this line by overhead conveyors, the nearly-finished bodies were carried over to another shop and landed neatly on the appropriate power unit as this, too, travelled along a conveyor.

Finally, the brand new shining cars were watched as they rolled off the end of the line, and after a rapid check of engine and brakes, were seen to plunge into a mass of traffic.

Although the welding interest was rather limited, this was a thoroughly worthwhile trip, particularly for those who were new to automobile production. There were, unfortunately, no free samples available.

John Thompson Ltd., Ettingshall—The thirty members making this visit were received by Mr. S. L. Nolan. A very comprehensive tour of the works had been arranged, with a view to covering as many of the Group's products as possible.

In the pressure vessel and boiler shops work in progress covered a wide variety of pressure vessels for the chemical and oil industries, and also boiler drums ranging from economic and package type boilers to very large units for Central Electricity Generating Board Power Stations. The application of automatic welding and non-destructive testing proved to be of great interest to the visitors. Also included was a visit to the Pipe Shops, where tubular elements, manifolds, and collector boxes, of entirely welded construction, were being processed.

It was noticeable that the visit to the Press Shop was of equal interest to the visitors. In this department very large presses and the most modern plant were seen working on a production-line basis, producing various pressings for the automotive and other industries. It was also evident that quite a number of the party found interest in recognizing such items as their own particular make of motorcar chassis frames being produced, and no doubt approved of the application of automatic and hand welding in the assembly of these items.

The hospitality of Messrs. John Thompson was greatly appreciated and it certainly was no formality, upon the conclusion of the visit, to express to them our sincere thanks for a most interesting visit.

Thompson Bros., Bilston—Twenty members of the Institute were received by Mr. E. Meeson on arrival and proceeded to visit the different departments of the works in small groups under the guidance of Mr. S. Boys, Mr. K. Hand and Mr. W. Camm. The many and various kinds of engineering construction work in progress were shown and explained to the visitors.

Of special interest were the modern methods of welding light alloys, engineering steels, stainless steels, and heat- and corrosion-resisting alloys by the inert-gas arc-welding processes. Fuel transportation equipment, ranging from the giant aircraft refuellers which carry over thirty tons of jet fuel in a welded aluminium alloy tank, to smaller ones for road use and other purposes was seen at all stages of construction and also under test their fuel filtering, dewatering, pumping, and metering equipment.

The visitors were later joined by Mr. A. M. Hutcheson, Mr. P. H. Thompson and other officers who were asked to accept the thanks of the visiting members and to convey to Mr. Howard Thompson (Past-President of the Institute) the kindest regards and best wishes of the Institute.

Dowty Mining Equipment Ltd., Tewkesbury—Twenty-six delegates took part in this visit. The works is ideally situated in the Wye Valley about 3 miles from Tewkesbury and comprises a number of industrial buildings of extremely pleasing design and layout.

The party was welcomed by Mr. Mills, Managing Director of the company, and the activities of the company in developing mining equipment and mining systems were effectively demonstrated by working models.

The visitors were then treated to a full-scale working display of equipment developed for centralized and semi-automatic control of the marshalling of railway goods wagons, after which they continued round the works to see the assembly of the company's main product—hydraulic pit props. The production of these props, which is still at a high rate, involves the use of a number of semi-automatic welding plants, including submerged-arc and CO_2-shielded arc.

An excellent tea was a most welcome culmination to an extremely interesting visit.

Special Lecture

Mr. Clarence E. Jackson, a Vice-President of the American Welding Society and Associate Manager of the Electric Welding Development Laboratories of the Linde Company, lectured to members of the Institute at a special evening meeting on Wednesday, 29th June.

He spoke on "The Science of Arc Welding"—an engineering approach to the effect of the welding technique on the performance of the arc welding process, with particular reference to submerged-arc welding, and ably answered questions from some of the audience of over 200.

A report of the lecture (which was a precis of the 1959 Adams Lecture of the A.W.S., published in the American Welding Journal, April–June, 1960) will be given in a later issue of B.W.J.

CONTRIBUTORS TO THE JOURNAL

W. G. John, R.C.N.C., M.R.I.N.A., is Deputy Director of Naval Construction, Admiralty.

He entered the Admiralty service in 1915 as an apprentice in Devonport

Yard, and from H.M. Dockyard School Devonport he was appointed a Naval Construction Cadet to the Royal Naval College, Greenwich, from which he graduated in 1923 with a First Class Certificate in Naval Architecture and was appointed an Assistant Constructor to the Royal Corps of Naval Constructors.

His early years were spent at sea, in H.M. Dockyard Portsmouth, and in the design sections of the Admiralty. Duties outside Admiralty Headquarters have included periods of Overseeing at Messrs. Scotts, Greenock, and later as Warship Production Superintendent, North West Area; Superintendent of Welding Development (Naval Construction) during the war period; and Fleet Naval Constructor Officer on the Staff of the Commander-in-Chief Mediterranean. Mr. John is now in charge of a group of the design sections in the Director General Ships Department, at Bath.

K. J. Clews, A.M.Inst.W., is a metallurgist who joined B.W.R.A. from the research department of I.C.I. (Metals Division). In the early days of atomic energy, he investigated the manufacture of fuel elements, and was then seconded to Marston Excelsior Ltd., where he was responsible for metallurgical control and research on the flux-dip brazing of aluminium alloys as well as the introduction and development of furnace brazing techniques for stainless steel, the Nimonic alloys, and titanium. More recently, his concern has been the welding of aluminium alloys, copper, and aluminium bronze, and also the gas-shielded tungsten-arc process for cutting metals. Mr. Clews holds patents relating to an arc-starting method and to an improved cutting torch.

P. F. Woods has been associated with the Welding Industry for some thirty years. He served his apprenticeship with Metro Cammell Ltd., after which he joined Nuffield Mechanisations & Aero. Ltd. as Welding Technical Advisor, where he was responsible for procedure, layouts, design, etc.

Following the closing of the firm in 1951, he became Welding Engineer with Fighting Vehicle Design and Research Division at Cranford Street, Smethwick, this firm being a subsidiary of the Guest, Keen & Nettlefold Group. (The name of the firm was subsequently changed to G.K.N. Group Services F.V.D.R. Division.) Here, he was responsible for several patents and improvements in the welding field, one concerning the use of metal powders as a brazing medium in connection with resistance welding.

In August 1959, he took up an appointment with Wilmot Breeden Ltd. In June 1960, Mr. Woods joined Fisher and Ludlow Ltd., as Assistant Welding Engineer in the Process Planning Office.

SCHOOL OF WELDING TECHNOLOGY

The following is a list of courses to be held in the School of Welding Technology at the Institute from September to March next. Each course marked with an asterisk* is already fully booked, but applicants can be placed on a waiting list for the next repeat.

1960

26th–30th September, D1/3—Welded Pressure Vessels*

10th–11th October, D13/2—Residual Stresses and Stress Relief

12th–14th October, D12/2—Practical Control of Distortion*

24th–27th October, D18/1—Metal Spraying

14th–17th November, D29—Welding Course for Supervisory Staff

28th November–2nd December, D3/2—Welded Design and Construction in General and Mechanical Engineering*

1961

16th–20th January, D15/2—Brazing Technology and Design

30th–31st January, D32—Design for Welding in Thermoplastics

13th–17th February, D5/3—Inspection and Testing*

27th February–3rd March, D22—Welding of Atomic Energy Plant

13th–17th March, D17/1—Advanced Course for Welding Engineers

27th–29th March, D28/1—Welding for Junior Management

Guests at School Courses

Beginning in the autumn, the School of Welding Technology will offer a limited number of free places to teachers of engineering subjects in Universities and Technical Colleges. A letter will shortly be addressed to the heads of the Engineering Departments of Colleges in and near London, inviting teachers to apply for places at courses to be offered during the coming winter.

W. G. John

K. J. Clews

P. F. Woods

BRANCH NEWS

South London

A.G.M. and Forum

The Annual General Meeting of the Branch, held at Princes Gate on Wednesday, 13th April, was preceded by a Forum "Prospect for Welding" and attracted a large number of members and visitors. The President of the Institute, Mr. E. Seymour Semper (who was also the first President of the South London Branch) was in the Chair, and he was supported by a Panel of Mr. B. K. Barber, Mr. A. A. Smith, and Mr. J. L. Hamilton (who was the first Secretary of the Branch).

After brief introductory statements by each member of the Panel, in which they outlined their own forecasts of future developments in welding, questions were invited from the audience. Discussion centred mainly around the question whether there should now be an integration and simplification of the many (over 50) welding processes and techniques that were already developed. Some thought that a reversion to the three main processes was essential if proper economic development was to be possible: perhaps the production of a universal machine that could be adapted for specific purposes. Opposing this was the more general view that the multiplicity of materials to be welded and their many applications required the building and development of numerous processes, though some simplification would be advantageous. It was generally conceded that the manually-operated processes were still the more commonly used and that attention should be given to the advancement of semi-automatic processes.

At the following A.G.M. the Chairman, Mr. P. J. E. Heath briefly reviewed the activities of the Branch (the Report of the Committee having been previously circulated) and declared the election of the Honorary Officers and Committee for the 1960–1 session. Mr. W. K. B. Marshall was unanimously re-elected Honorary Auditor and was thanked for his past services. Mr. Heath then introduced the new Chairman, Mr. J. Hinde, who then took the Chair. Mr. Hinde thanked the members

for the honour given him and praised his predecessor for the services he had rendered to the Branch.

North London

Annual General Meeting

The Branch held its Annual General Meeting on Wednesday, 20th April at Princes Gate, when 85 members and visitors were received by the President, Mr. R. W. Ayers, the Chairman, Mr. C. R. Thatcher, and the Committee.

The evening started at 5.30 p.m. with a Conversazione at which six displays of recent developments in the field of welding and cutting were on view:

Pulsonic Welding—A new British development for the joining of similar and dissimilar materials. Samples of joints made in material of 0·015 in. thick and less were shown.

Space Age Construction—A display of honeycomb and sandwich construction in a variety of materials, including stainless steel, aluminium, titanium, etc. The resistance welded and brazed samples provided an interesting display of the future of the industry in the development of missiles, rockets and space stations of the future.

Argonarc Welding and Cutting—Exhibits of tungsten-arc cutting showed the progress which has been made in the cutting of stainless steel. The edge preparation of a $\frac{1}{8}$ in. plate was made at 45 in/min. The edge was smooth and free of dross.

The argonarc spot welding samples showed joints in aluminium, stainless steel, mild steel, and titanium.

Oxygen cutting—An oxy-propane blowpipe used to cut 60 in. of steel was displayed alongside the Harris Calorific Cutomation cutting outfit. This latter equipment shows considerable savings in fuel consumption and enables high profile cutting speeds to be obtained.

CO_2 Welding—Examples of CO_2 fine wire welding showed the potential of this new process. The emphasis was on production welds made with the new equipment now available in this country.

A further display was set out showing examples of new or unusual welding applications.

Also present at each stand were representatives of the firms, and members of the committee assisted with technical discussions. Refreshments were provided, and at 7.0 p.m. the members attended the A.G.M. Mr. R. W. Ayers, President, took the chair, and the General Meeting was most ably dealt with by Mr. Thatcher, Chairman, the Secretary, Mr. J. F. Gibbs, and Mr. F. Thomas, Acting Treasurer, in the absence of Mr. S. P. Bennett, who has unfortunately been in hospital.

Following the reading and acceptance of the 1959 A.G.M. minutes, the Secretary reported on the state of the Branch, and referred to membership and attendance. The Assistant Secretary, Mr. R. B. Whalley, had provided attendance records which Mr. Gibbs presented, when the members learned that the average attendance over the last seven meetings was: members 45·6, and visitors 21·8, totalling 67·4 per meeting.

The Acting Treasurer dealt with the accounts of the Branch very well, and the A.G.M. was closed to permit all members to return to the exhibition. At 7.30 p.m. cocktails were served, and a most enjoyable evening passed all too quickly, the liquid refreshments bar closing at just after 9.0 p.m. It was the unanimous opinion of all members and visitors that the entire evening had been most enjoyable, and most excellently organized. Credit for this in no small measure is due to Mr. F. Coplestone, Programme Secretary, who had done a fine job in a very short time.

R.B.W.

South London North London

Joint Annual Dinner

The Annual Dinner of the North and South London Branches of the Institute was held on Thursday evening, 21st April, in the Connaught Rooms, London, W.C.2, when an excellent evening was spent by over 400 members and guests. The chair was taken by Mr. R. W. Ayers, President of the North London Branch, who introduced the speakers to the gathering. Having proposed the Loyal Toast, he introduced Mr. A. A. Shenfield, Economic Director, Federation of British Industries, who spoke about the economic growth of Britain's industry. The technical societies, which were introduced primarily in Britain, were associated very closely with this expansion, for developments in technology were vital to increased production. Yet, compared with many other countries, particularly Germany and Japan, British Industry seemed to lack a sense of urgency—it was, he thought, too fairminded in a commercial sense, and showed less tendency for innovation and initiative. If the U.K. could increase its industrial economy up to about 4% per annum it need have no fear of European Free Trade. And this would be possible if the work of the technical societies, such as the Institute of Welding and the Research Association was more widely recognized and applied.

The response came from Mr. E. Seymour-Semper, President of the Institute of Welding, who spoke of the way welding had played a big part in the economics of the country. He also compared the educational facilities, in regard to welding, offered by many other countries with the meagre opportunities available in Britain. In reminiscent vein, he recalled the first Dinner of the South London Branch in 1947 and of the members who had attended. One great man was present by his side, he said—Sir Charles Lillicrap; another great and respected man had passed on—Sir William J. Larke.

The toast to the guests was proposed by Mr. N. L. G. Lingwood, who praised the organizers for both the excellent Conversazione at Princes Gate on Wednesday evening (North London A.G.M.) and the Dinner. He paid tribute to the fine work done by the Senior representatives of the Institute and also those stalwarts and champions of Welding, the Editors of *Welding and Metal Fabrication* (Mr. R. N. Thompson) and the *British Welding Journal* (Mr. C. Rowland Harman). In jocular vein, he spoke of the speaker to follow, Mr. J. Strong, and said it was not fair that he always wangled "the last word"! In reply, Mr. J. Strong, Past President of the Institute, spoke of the years the Institute has been in being, of the Founder members, and gave a word picture of its history. He also, in jocular vein, stated that he was pleased to get the last word over on Mr.

Some members of the North London Branch Committee, and two of the displays at the Annual Meeting

Lingwood, and that each of them had been fighting for the opportunity to have "the last word" for a full 25 years of friendship and business acquaintanceship, in the welding field. The formal side of the Dinner was then closed, and members and guests got together for informal chats, completing what had proved to be a splendid evening, excellently organized by a Committee from both North and South Branches, headed up by that very fine organizer, Mr. J. Hooper.

R.B.W.

INTERNATIONAL INSTITUTE OF WELDING

1960 Annual Assembly

The Annual Assembly of the International Institute of Welding was held by invitation of the Belgian Institute of Welding at Liège, from 13th–19th June, 1960. The President of Honour was H.R.H. Prince Albert of Belgium, Prince of Liège. The assembly attracted more than 700 people from 23 countries and took place at the Palais des Congrès, a magnificent and exceptionally convenient site on the banks of the Meuse.

This was the second visit of the International Institute to Belgium, where its first Annual Assembly was held in 1948, on that occasion at Brussels.

As usual, the meetings of the 15 technical commissions made up the greater part of the programme. Each held four sessions and discussed a large number of reports, many of which will in due course be issued for publication.

There were several novelties in the organization of the meeting. First there was no open meeting for the presentation of papers, but instead three of the commissions held extended meetings called Colloquia, the attendance of which was limited to 120, the proceedings consisting of the presentation and discussion of pre-printed papers on technical subjects.

Commission I (Gas Welding and Allied Processes) discussed papers on metal spraying; Commission V (Testing, Measurement and Control of Welds) the inspection and testing of resinous materials (plastics); and Commission X (Residual Stresses and Stress Relieving) the influence of residual stresses on stability of welded structures and structural members.

At each Colloquium a Belgian *rapporteur* presented the papers, the authors replying to the discussion. British authors who contributed papers were for Commission I—Dr. T. P. Hoar, Mr. A. R. Old and Mr. W. E. Ballard, and for Commission X—Professor M. Horne.

Another novelty was a series of five lectures from five different countries on the same subject, "*The Welding of Very Thick Materials*". The British lecturer was Dr. H. Harris.

The customary international exhibition of publications and photographs of welding interest from member countries of the I.I.W. was larger than usual and was exceptionally well arranged and displayed by the Belgian Organization Committee.

The Liège International Fair was in progress during the time of the Assembly and on one evening members had the opportunity to visit the Fair and inspect the many stands set up by the welding supply manufacturers.

At the end of the Assembly Mr. W. Edstrom (Sweden), President Elect, succeeded Dr. U. Guerrera (Italy) as President of the Institute.

Mr. F. L. Plummer (U.S.A.) and Dr. G. Vedeler (Norway) succeeded Dr. A. Rapatz (Austria) and Professor Radojkovic (Yugoslavia) as Vice-Presidents, Professor Jaeger (Netherlands) was elected Honorary Treasurer in succession to Mr. Edstrom and Mr. G. Parsloe (U.K.) was for the fifth time re-elected Secretary-General.

W. Edstrom, President of I.I.W.

In the week after the Assembly two parties of I.I.W. members toured industrial and historic areas of Belgium in tours organized by the Belgian delegation.

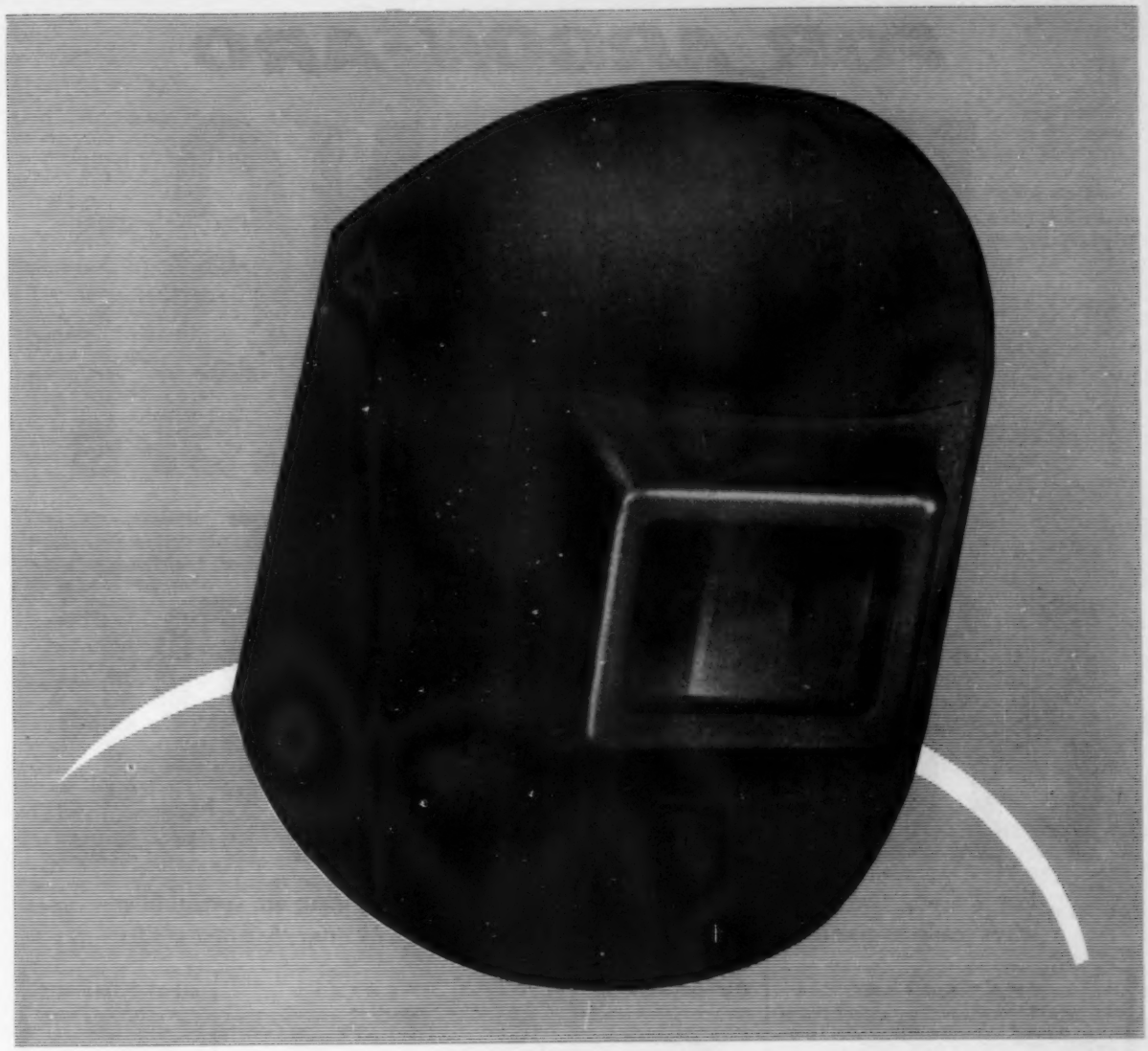
The illustrations show three of the hard-working technical commissions in action, one against the background of ships passing on the river.

The next Annual Assembly is to be held in New York from 11th to 18th

Commission XV—"Fundamentals of Design and Fabrication for Welding" in session. The British delegate, Dr. F. Koenigsberger is facing the camera at the extreme left

Commission VI—"Terminology" in session. Second from the left is Mr. E. W. Harding, the British delegate

Commission XII—"Special Arc Welding Processes" in session



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Most welders prefer Murex helmets because they are right for protection, comfort and strength. They are made of high grade fibre or bonded laminated plastic and are completely shockproof, light in weight and comfortable to wear. Each helmet is fitted with an adjustable headband having an automatic locking device which enables the helmet to be held in the "up" position as long as desired. A patent Murex glass holder provides a dual purpose facility in the plastic type. The coloured filter glass can be raised or lowered in a fraction of a second so that the welder can sight his work right up to the moment of striking the arc.
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FOR ARGON-ARC WELDING OF HIGH NICKEL ALLOYS USE THE RIGHT FILLER WIRE

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MATERIAL	ARGON-ARC FILLER-WIRE
MONEL* *corrosion-resisting alloy*	60 MONEL
AT nickel	61 nickel
Low-Carbon AT nickel	61 nickel
DURANICKEL* *age-hardenable nickel*	61 nickel
K MONEL* *age-hardenable corrosion-resisting alloy*	64 K MONEL
NI-O-NEL* *corrosion-resisting alloy*	65 NI-O-NEL
CORRONEL* 210	CORRONEL 210
CORRONEL* 220	CORRONEL 210
CORRONEL* 230 *corrosion-resisting alloys*	CORRONEL 230

MATERIAL	ARGON-ARC FILLER-WIRE
INCONEL* *oxidation-resisting alloy*	NC-82
INCOLOY*	INCO-WELD 'A'*
INCOLOY* DS *heat-resisting alloys*	INCO-WELD 'A'*
NIMONIC* 75	NC-82
NIMONIC* 80A *high-temperature alloys*	NC-90
NIMONIC* 90	NC-90
BRIGHTRAY* 'B'	NC-82
BRIGHTRAY* 'C' *high-temperature*	NC-82
BRIGHTRAY* 'H' *electrical resistance*	NC-82
BRIGHTRAY* 'S' *alloys*	NC-82
BRIGHTRAY* 'F'	INCO-WELD 'A'*

*Trade mark

We have available a 16-mm sound film in colour entitled '*Welding of Wiggin High-Nickel Alloys*' which is available without charge for showing to engineering societies, training classes, etc. Write for details.

SEND FOR THIS BOOKLET

Full details of welding techniques by all processes are given in our welding handbook, '*Welding, Brazing and Soldering of Wiggin Nickel Alloys*'. Write for your copy.

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April, 1961, dates which overlap with the opening of the Spring Meeting of the American Welding Society, also to be held in New York.

OTHER SOCIETIES

British Acetylene Association

The Annual Luncheon of the Association was held at the Connaught Rooms on Thursday, 5th May, under the Chairmanship of Mr. John Strong, the President.

The toast to the Association was proposed by Sir Charles Goodeve, F.R.S., Director of the British Iron and Steel Research Association, and the response was made by the President.

Physics amalgamation

The Institute of Physics and The Physical Society were amalgamated on 17th May as one body, to be known as "The Institute of Physics and The Physical Society".

The first President of the amalgamated body is Sir John Cockroft, and the four Vice-Presidents are Dr. J. Topping, Dr. W. H Taylor, Professor R W. Ditchburn, and Mr. A. J. Philpot. The executive officers are Dr. H. R. Lang (Secretary), Dr. A. C. Stickland (Editor and Deputy Secretary), and Mr. N. Clarke (Deputy Secretary).

The offices of the new body are at 47 Belgrave Square, London S.W.1. but offices at 1 Lowther Gardens, South Kensington are being retained for the present.

NEWS FROM INDUSTRY

Isotope Research

The U.K.A.E.A. Isotope Research Laboratories at Wantage were officially opened on 16th May by Lord Hailsham, the Minister for Science. The main task of the laboratories is research into new and improved uses of radio-isotopes and irradiation techniques. In addition, the Isotope School, for the training of students, is now housed at Wantage. Investigations are already being carried out on the sterilization of food and medical products, insect and pest control, and problems of coastal erosion and silting. In the industrial field, radioactive isotopes are finding increasing applications in spectrometry, thickness measurements, investigations on turbulent flow, determination of soil density and moisture content, and the like. The Laboratories house 23 experimental cobalt cells which can be used for dosing materials from other establishments and industrial clients, as well as for internal research.

Cover Illustration

A suite of 3 hot caves for producing caesium-137 for industrial and medical radiography

A prototype package irradiation plant has been set up for the automatic handling and irradiation of standard (14×12×9 in.) packages. The plant has a capacity of about 100 cu. ft per day at a sterilizing dose of 2·5 megarads.

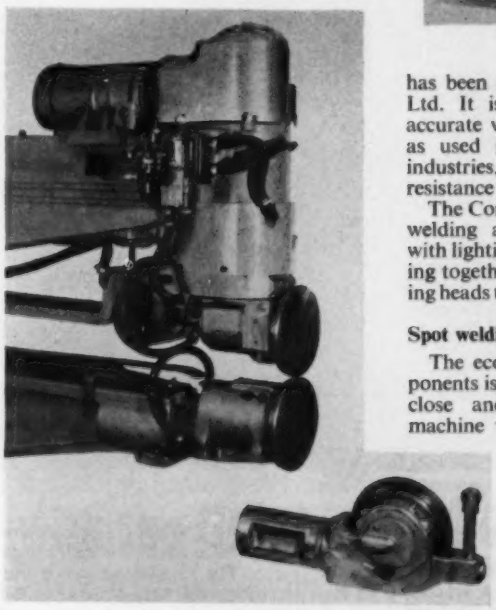
Engineering materials and design

The success of the 1st Engineering Materials and Design Exhibition, held at Earls Court in February, has led the organizers to arrange a 2nd Exhibition and Conference in Hall D at Earls Court between 13th and 18th November 1961. It is hoped then to repeat the Exhibition bi-annually.

NEW PLANT AND EQUIPMENT

Universal roll-seam welder

The Belgian SAGU 125 air-operated universal roll-seam welder is now being produced in Britain by Electro Mechan-Heat Ltd. The machine has a capacity of two 13 s.w.g. mild steel or two 14 s.w.g. stainless steel sheets, with throat depths from 19½ to 39 in. The maximum welding load between the electrode wheels is 1625 lb, pneumatically applied and controlled by a 2-stage foot switch; the first stage applies the pressure, and the second initiates the welding current.



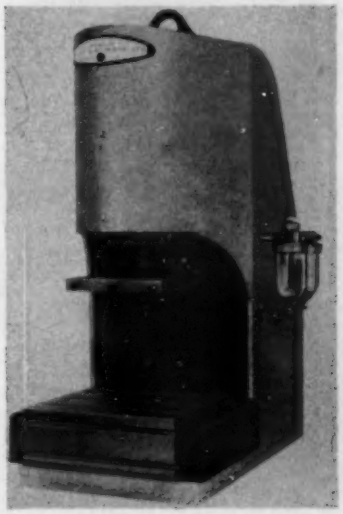
Electro Mechan-Heat universal roll-seam welder

A single-phase, 400/440V, stacked core transformer provides power ratings of 50–160 kVA.

The design of the machine is simplified by locating the drive motor above the upper arm. Adjustment for longitudinal or circumferential welding is made by rotating the upper head through 90° and by changing the lower arm extension. A reversing switch allows circumferential welds to be made in either clockwise or anti-clockwise directions.

Resistance welding and brazing machine

A new 25–60 kVA spot and projection welding and resistance brazing machine



has been produced by Hirst Electronic Ltd. It is specially designed for the accurate welding of small components, as used in the motor and electrical industries, and for closely controlled resistance brazing.

The Company are also manufacturing welding and assembly benches fitted with lighting, heating, and air-conditioning together with single or double welding heads to suit individual requirements.

Spot welding control

The economic spot welding of components is increasingly dependent on the close and accurate control of the machine variables. Once the optimum settings have been found they must be maintained accurately during the production cycle. The 'Synchrospot', a new four-channel synchronous control introduced by Sciaky Electric Welding Machines Ltd., permits welding speeds of more than 750 spots per minute with a guaranteed accuracy of 100%. In addition, the control is stated to eliminate transient currents, thus reducing the power demand. By strict control

in this way the duty cycle is improved and there is more consistent tip wear leading to longer life and fewer interruptions for dressing or changing.

The control comprises a 4-stage Dekatron timer, a built-in phase-shift heat control, which eliminates tap changing, and an Ignitron contactor. The timer provides a range of 1 to 90 cycles for pre-set, weld, forge, and off. The cabinet housing the complete controls, dials and switches is designed for use with static or portable machines and for floor or wall mounting.

Improved profile cutting

The 'Cutomation' system has now been applied to the British Industrial Gases Ltd. dual-carriage type 'Cub' Mk. II profiling machine. The improved model enables faster and more efficient cutting to be done with savings in fuel consumption.

The magnetic tracing head has a 4 : 1 reduction unit with $\frac{3}{8}$ and $\frac{1}{2}$ in. tracing spindles, and $\frac{1}{4}$ and $\frac{1}{2}$ in. spindles are available for hand tracing.

Combined welding and cutting outfit

One of the results of the agreement between British Industrial Gases Ltd and Harris Calorific Co. of Ohio has been the availability in Britain of equipment that has had extensive field trials in the U.S.A.

B.I.G. have recently announced that they are now making a combined welding and cutting torch, the 'Economatic 50–2', that provides substantial economies in gas consumption. On the automatic version of this torch the welding flame, after it is lit, can be reduced to a minute pilot light during 'off' periods by releasing a thumb lever. By simply unscrewing the mixer assembly and replacing it with a cutting head, the blowpipe is converted to a cutting torch.

The nozzles, which are the same as those used on the BIG Series 13–90 torches, permit welding of steel up to 1 in. thick, and the cutting head can deal with steel up to 3 in. thick.

Heating with electrodes

A means of rapid and concentrated heating of metals before welding or manipulation is provided by a new electrode 'Thermees' produced by the English Electric Co. Ltd. The electrode is all-positional and is used like a normal welding electrode. It operates on d.c. or a.c. (preferably with a.c. voltage of 80–85 V). The amount of heat applied can be controlled by the rate of travel and the number of passes of the electrode.

Section forming

An all-steel section rolling machine, designed specifically for the rapid forming of rings from angles, tees, channels, rounds, and squares, is now marketed by F. J. Edwards Ltd. It will accommodate $2\frac{1}{2}\times2\frac{1}{2}\times\frac{3}{8}$ in. angles, 4×2 in. channels or $1\frac{1}{2}$ in. dia. rounds within the

standard 10 in. dia. rollers which are made from surface hardened spheroidal graphite iron. The 5 h.p. drive motor and 2 h.p. pressure roller adjustment motor are both fitted with magnetic brakes to ensure positive control.

Hot-state radiography

Pantak Ltd. have concluded an agreement with Sierex Ltd. for the marketing and servicing of the Siemens 15 meV Industrial Betatron. This fully mobile unit is capable of examining steel thicknesses of up to 16 in.

An important aspect of the use of the Betatron is the use of an enlargement technique, which gives an extremely high flaw sensitivity. Enlargements of up to four times normal size are possible, so that fine flaws which would otherwise be difficult or impossible to observe can be detected. A further significant development is the application of hot state radiography to welds or billets. This opens up new possibilities for establishing production techniques, with the elimination of costly defects.

Thermo-setting silver cement

In collaboration with CIBA (A.R.L.) Ltd., Johnson, Matthey & Co. Ltd. have produced an Araldite-based preparation containing silver in flake form. Silver cement FSP49 can be used to provide a conducting bond between any materials that will withstand the minimum curing temperature of 80°C. After curing the material is highly resistant to water and organic solvents. With metals, a single lap joint can be expected to give a joint strength of 1000–2000 lb/sq.in.

STUB ENDS

▶ Ford Motor Company (U.S.A.) are considering the development of the Ford 'Levacar', a wheel-less, multi-passenger vehicle that slides along rails on a thin film of air, and would be capable of attaining speeds up to 500 miles/hr.

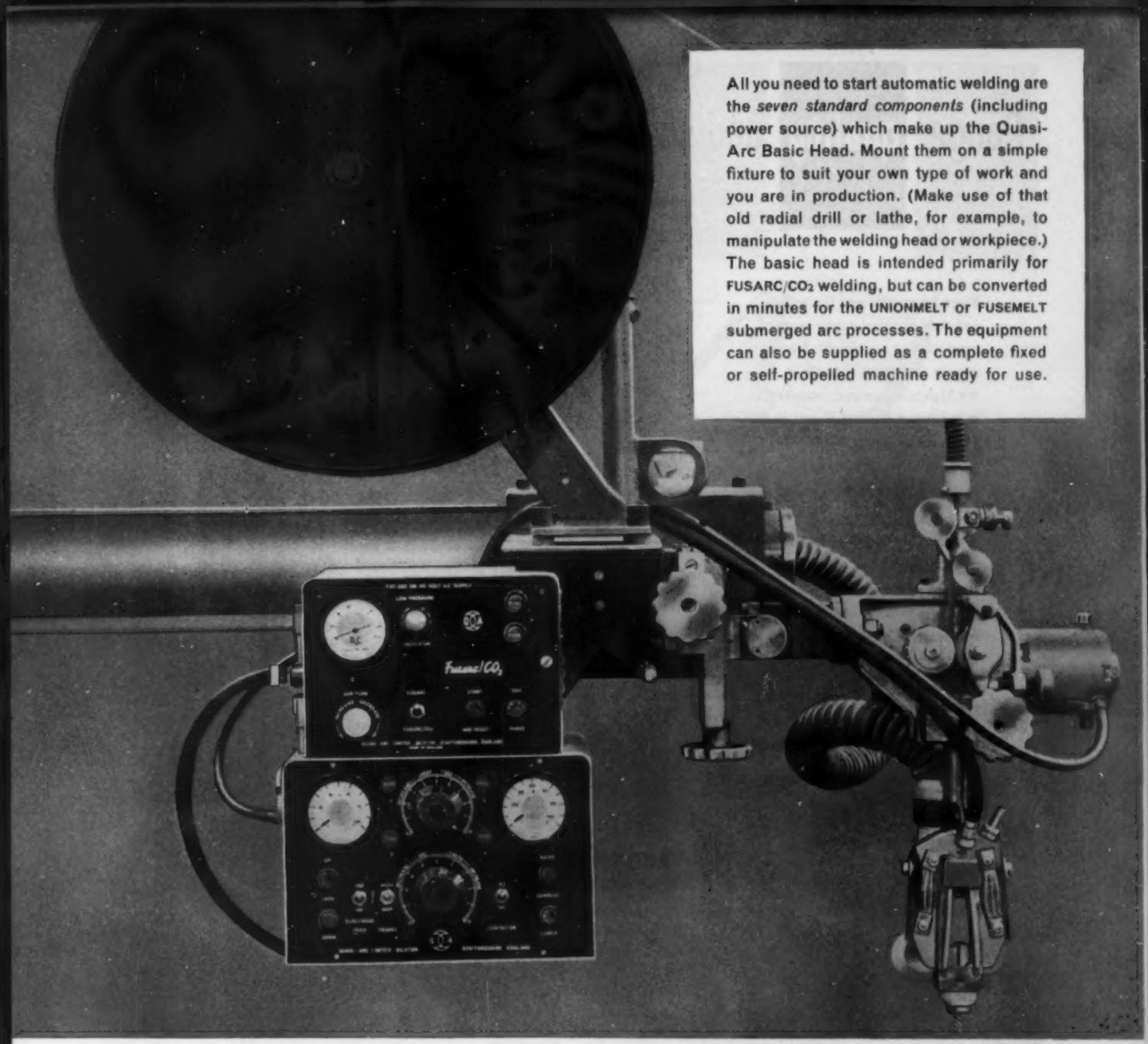
▶ Stubs Welding Ltd. has been formed as a subsidiary of Peter Stubs Ltd. of Warrington. The new company is marketing a range of welding rods and low-current electrodes suitable for the welding and repair of ferrous and non-ferrous castings.

▶ Inspection of all-welded aluminium hatch-boards, after continuous and arduous service in m.v. *Enugu Palm* for 2 years, shows no sign of weld or other failure, and there is no indication of corrosion.

▶ A new division of R. J. Richardson & Sons Ltd. has been formed, known as Site Shotblasting (Gt. Britain). This will take care of the shot blasting on site of work too large to be dealt with by transport to the works.

▶ On 10th June 1960, the A.P.V. Company Ltd. celebrated the 50th anniversary of its founding by Dr. Richard Seligman. In a booklet 'APV 1910–1960' the origin and growth of APV (originally The Aluminium Plant and Vessel Co. Ltd.) is described, and many of the special developments in aluminium welding and in stainless steel fabrication, for which the company is famed, are illustrated.

▶ The Sheffield Smelting Company Ltd., well known for their silver solders and other precious metal products, celebrates its bi-centenary this year. The company was founded in 1760 by John Read, who set up in business, in his own name, as a refiner.



All you need to start automatic welding are the *seven standard components* (including power source) which make up the Quasi-Arc Basic Head. Mount them on a simple fixture to suit your own type of work and you are in production. (Make use of that old radial drill or lathe, for example, to manipulate the welding head or workpiece.) The basic head is intended primarily for FUSARC/CO_2 welding, but can be converted in minutes for the UNIONMELT or FUSEMELT submerged arc processes. The equipment can also be supplied as a complete fixed or self-propelled machine ready for use.

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NEW LOW-COST AUTOMATIC WELDING PLANT. Quasi-Arc now introduce an entirely new concept in automatic welding plant. With the Basic Head you can construct an automatic welding installation to meet your own special requirements — at a much lower cost than before. The plant can be adapted progressively to meet production changes by buying conversion parts independently as required. For full details write for Quasi-Arc Technical Circular No. 204.

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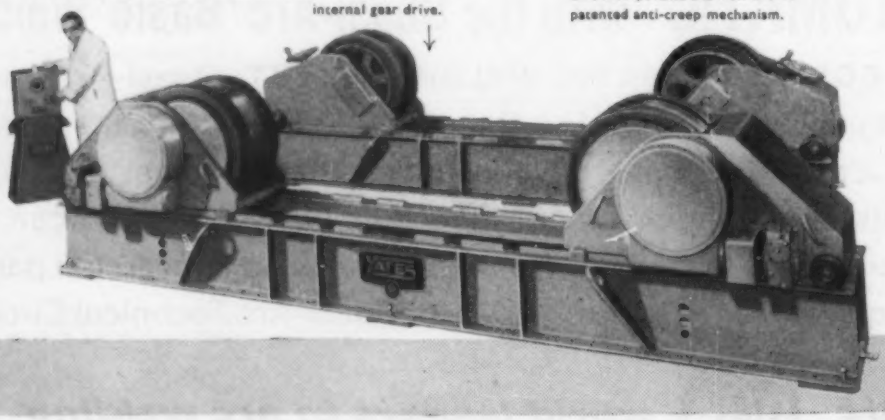
The NEW Yates patented Twin Pillar Column with retractable Boom, of rigid design to obviate any deflection at the weld point. The machine illustrated has an 18 ft arc height and a 16 ft retractable Boom movement. Controls for all movements of the Column and Boom and Rotator set are at the end of the Boom and are also duplicated at ground level.

150 ton capacity rotated Self Propelled Carriage Rotator set. With this design the carriages move themselves inwards or outwards to suit any vessel diameter. Note the large projection clearance on the wheels which is achieved by an internal gear drive.

A Yates 20 ton Travelling Self-aligning Rotator set with integral bogies. The idler unit incorporates the well known patented anti-creep mechanism.



Current WELDING LITERATURE

Book Reviews

Additions to the Institute Library

Trade Publications

CONTENTS OF PERIODICALS RECEIVED

This section is intended to give a survey of the current welding literature received by the Institute of Welding Library. The contents lists are not exhaustive; only the main articles in welding journals are listed, and reprints from other journals and short notes are generally excluded. In addition, welding articles from other periodicals are listed. Abstracts of welding literature are given in the Bibliographical Bulletin of Welding and Allied Processes, *published by the International Institute of Welding, and details of this may be obtained from the Secretary of the Institute of Welding.*

Welding Journals

Australian Welding Journal, 1960, vol. 3, No. 6, February

Dynamics of welding production management, D. M. Kerr (8–15)

Revised pre-examination requirements and syllabi—Federal certification committee invites comment (18–23)

Automatic Welding (U.S.S.R., translated by the B.W.R.A.), 1959, September

Automatic submerged arc fillet and butt welding with three electrodes, A. A. Kazimirov, V. Kh. Bondar', V. V. Meshkov and V. P. Lozovskii

The substructure of low-carbon welds, B. S. Kasatkin and G. F. Darovskii

Certain technological methods of improving the strengths of welded joints under vibrating loads, A. E. Asnis

Pre-stressed welded tanks and experience of their use, G. V. Raevskii

Electro-slag welding of ageing chromium–nickel–aluminium stainless steel, B. I. Medovar, A. N. Safonnikov, E. Ya. Bel'kin and O. A. Sharov

Direct joining of tubular section components, V. I. Novikov, V. A. Kovtunenko and O. I. Shumitskii

Longitudinal welding deformations in pre-stretched and pre-compressed plates, V. I. Tereshchenko

The book 'An approximate theory for welding deformations and stresses', G. B. Talypov and I. P. Baikova

Electro-slag welding of circumferential joints in thick-walled containers, V. I. Rabinovich, M. G. Bel'for, Yu. D. Gupalo, O. O. Rozenberg and V. M. Khrundzhe

Features of the twin arc process using fine electrode wire, V. N. Sherstyuk

The effect of pass-by-pass peening on austenitic weld metal quality, F. G. Gonserovskii

Automatic hardfacing of blast furnace charging bells using vertical rotating machines, M. A. Tylkin, V. I. Sivak, I. F. Parfent'ev and M. A. Kropp

The State Standards on welding fluxes, V. V. Podgaetskii and V. N. Kolisnyk

An ultrasonic machine for continuous weld inspection in welded structures, Yu. M. Taran

Welding Journal (U.S.A.), 1960, vol. 39, April

Fabrication, erection, welding and testing of largest welded T-1 steel spiral casings, E. L. Seeland (307–313)

Development of forming and joining techniques for corrugated sandwich structure, H. Smallen and R. P. Romaine (314–321)

How to interpret fractures in aluminium weld metal, W. L. Burch (322–327)

Preheated welding wires and their effect on welding characteristics, W. T. DeLong and others (328–333)

Design, welding procedure and fabrication of concentric molten-sulphur pipe line, C. M. Cockrell and J. M. Shilstone (334–342)

Successful welding of foil gauges, G. R. Archer (343–347)

The characteristics of flat welding wire, V. H. Godfrey (348–350)

Profiling of sprocket segments with the electronic oxygen-cutting machine (351–353)

The science of arc welding, C. E. Jackson (129*s*–140*s*)

Welding low-carbon martensite, W. P. Hatch and others (141*s*–146*s*)

Notch sensitivity in high strength sheet materials, G. M. Orner and C. E. Hartbower (147*s*–159*s*)

Notch-ductile weld metal for dynamically loaded T-1 steel structures, J. S. Kobler (160*s*–171*s*)

Evaluation of laboratory fatigue studies for welded structures, W. H. Munse (172*s*–175*s*)

Welding Production (U.S.S.R., translated by the B.W.R.A.), 1959, October

Welding Technology in the German Democratic Republic, W. Gilde

Investigation into Welding Technology of 5–50 Ton Travelling Cranes Main Girders, Ts'ien Tsu-Ni

The Role of the Central Welding Institute of the German Democratic Republic in Developing Use of Plastics, G. Schwarz

On the Scientific and Research Work of Chinese Students, G. A. Nikolaev

Energy distribution in the Friction Welding of Steel Bars, V. I. Vill

The Heating and Cooling of studs under Butt Friction Welding, N. N. Rykalin, A. I. Pugin and V. A. Vasilieva

Power and Heating in Friction Welding of Thick-Wall Steel Pipes, A. S. Gelman and M. P. Sander

Power and Heat Parameters of Friction Welding, R. I. Zakson and V. D. Voznesenskii

Friction Welding in the reconditioning Worn Components, Kh. A. Tyayar

Submerged-arc Welding of Pipe Branches to Fire Tubes, F. F. Benua

Influence of Residual Stresses and Strain on Mechanical Properties of Welds, L. I. Gladshtein

Determination of Heated Zone Length Under Resistance Seam-Butt Welding of Pipes, B. D. Zhukovskii

Powder-cutting of Stainless Steels with Using Natural Gas, I. D. Davydenko, G. F. Kulichenko and M. M. Eremenko

Comparison of Some Electrodes for Cold Welding of Cast Iron, S. A. Narskii and M. A. Grishin

Automatic Hard Facing and Toughening of Rolls and Shafts, M. A. Tylkin and V. I. Sivak

Self-centring Nozzles for Oxy-acetylene Cutters, B. I. Smirnov

Bend Tests for Welded Joints, A. S. Falkevich

Greater Attention to Soldering in the training of Welding Engineers, E. M. Eskin.

Programme Controlled Machines for Oxygen-Cutting, G. A. Kravetskii and N. D. Raikov

Soviet Welding Literature, V. A. Nevskii

Zvaranie (Czechoslovakia), 1960, vol. 9, April

Welding of the Czechoslovak petroleum pipeline, L. Pliva (97–99)

Productivity increase in resistance welding, M. Vitavsky (99–103)

Is the resistance fusion welded joint decarburized? K. Malik and J. Hrivnak (103–107)

Vacuum-tight joints welded by means of a welding press, T. Zrna (107–111)

Application of manual arc welding and forcible weld forming in tool production, M. Mosny (111–112)

Other Journals

All-position arc welding, A. Lesnewich (*Metal Progress* (U.S.A.), 1960, vol. 77, March, pp. 122–124, 158, 160)

Puddle welding: application of argon-arc fusion spot-welding to aircraft stainless-steel assemblies (*Aircraft Production*, 1960, vol. 22, April, pp. 145–148)

Atomic hydrogen welding, E. N. Simons (*Engineering Materials and Design*) 1960, vol. 3, April, pp. 226–228)

Welding today: methods and machines in current use, E. C. Pigott (*Iron and Steel*, 1960, vol. 33, April, pp. 155–159)

Flash butt welds in aluminium are safe and reliable (*Steel* (U.S.A.), 1960, vol. 146, March 14, pp. 110–111)

Honeycomb, Part 2, How to fasten honeycomb sandwich. Nonstructural uses of honeycomb, P. J. B. Stevens and L. M. Polentz (*Materials in Design Engineering* (U.S.A.), 1960, vol. 51, April, pp. 123–126, 167–168)

Using radioisotopes safely, V. A. Broadhurst (*Machine Shop Magazine*), 1960, vol. 21, April, pp. 237–239)

Characteristics of the ultrasonic radiation field, with special reference to immersion testing (*Solus Schall News on Non-Destructuve Testing*, 1960, No. 16, March, pp. 4–11)

New eddy current test for tubing, B. B. Burd (*Metal Progress* (U.S.A.), 1960, vol. 77, April, pp. 101–103)

Continuous fluroscoping spots pipe weld defects (*Steel* (U.S.A.) vol. 146, April 11, p. 96)

Welding properties of steels, J. Lomas (*Machinery Lloyd*, 1960, vol. 32, April 16, pp. 30–31, 33)

Columbium added to steel makes pipe more weldable (*Steel* (U.S.A.), vol. 146, April 11, p. 102)

Design of piping systems for high pressure and high temperature, S. K. Ghosh Hazra (*Journal of the Institution of Engineers* (India), 1960, vol. 40, No. 6, Part 2, February, pp. 219–230)

Fabrication of a Zircaloy-2 in-pile pressure tube, J. G. Goodwin (*Metal Progress* (U.S.A.), 1960, vol. 77, April, pp. 93–96)

Fatigue criteria in welded structures (*Engineering*, 1960, vol. 189, April 15, pp. 512–513)

The welding of lead pipework (*Torch*, 1960, No. 22, pp. 10–15)

Welded design offers savings in machine construction (*Iron Age* (U.S.A.), 1960, vol. 185, March 24, pp. 92–94)

Hardfacing, A. E. N. Houghton (*New Zealand Engineering*, 1960, vol. 15, February 15, pp. 67–71)

Diffusion bonding: a new way to join critical parts, W. P. McQuillan (*Materials in Design Engineering* (U.S.A.), 1960, vol. 51. April, pp. 14–16)

Five ways to seal glass to metal, W. A. Gleason (*Materials in Design Engineering* (U.S.A.), 1960, vol. 51, April, pp. 120–122)

Russians weld rivets with coated electrodes (*Steel* (U.S.A.), vol. 146, April 11, p. 100)

Modern practice of flame hardening, M. R. Scott (*Metal Progress* (U.S.A.), 1960, vol. 77, April, pp. 69–73)

Non-mechanical jointing of metals, G. Fitzgerald-Lee (*Engineering Materials and Design*, 1960, vol. 3, May. pp. 291–297)

The flame hardening of gears, J. T. Howat (*Metal Progress* (U.S.A.), 1960, vol. 77, April, pp. 76–78)

Changes in Calder fuel elements under irradiation, V. W. Eldred, A. Stuttard, and J. Skinner (*Nuclear Engineering*, 1960, vol. 5, April, pp. 160–163)

The electron beam as a production tool (*Engineering*, 1960, vol. 189, April 22, pp. 556–557)

Why metals break and what to do about it, D. Peckner (*Materials in Design Engineering* (U.S.A.), vol. 51, April, pp. 127–142)

ADDITIONS TO THE LIBRARY
BOOKS AND PAMPHLETS

AMERICAN SOCIETY FOR TESTING MATERIALS. *Specifications for coated and uncoated iron and steel sheet and strip; steel sheet and strip, metallic coated steel sheet, wrought iron sheet, metallic coating materials.* Philadelphia, A.S.T.M., September 1959. (Price $3.00)

AMERICAN WELDING SOCIETY. *Welding ferrous materials for nuclear power piping.* A committee report (D.10.5–59). New York, A.W.S., 1959. (Price $1.50)

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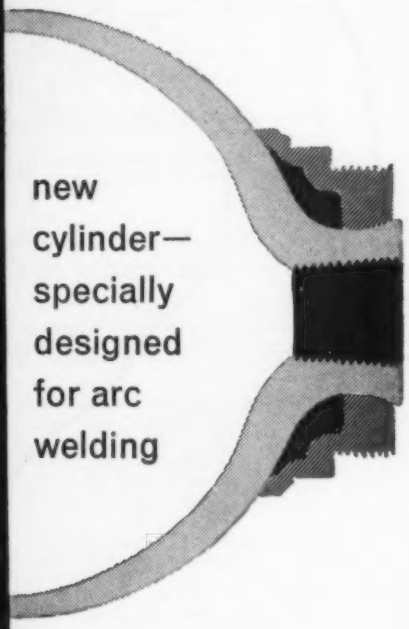

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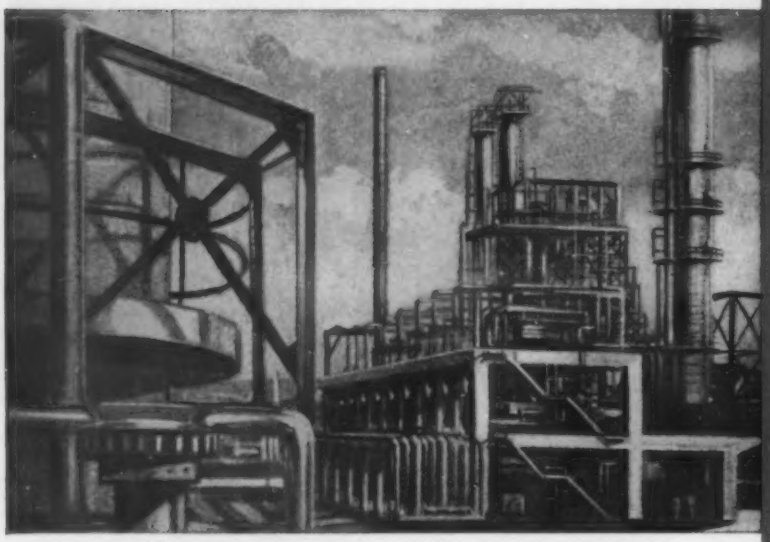

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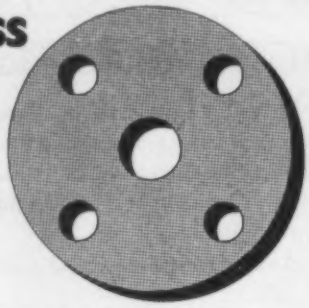

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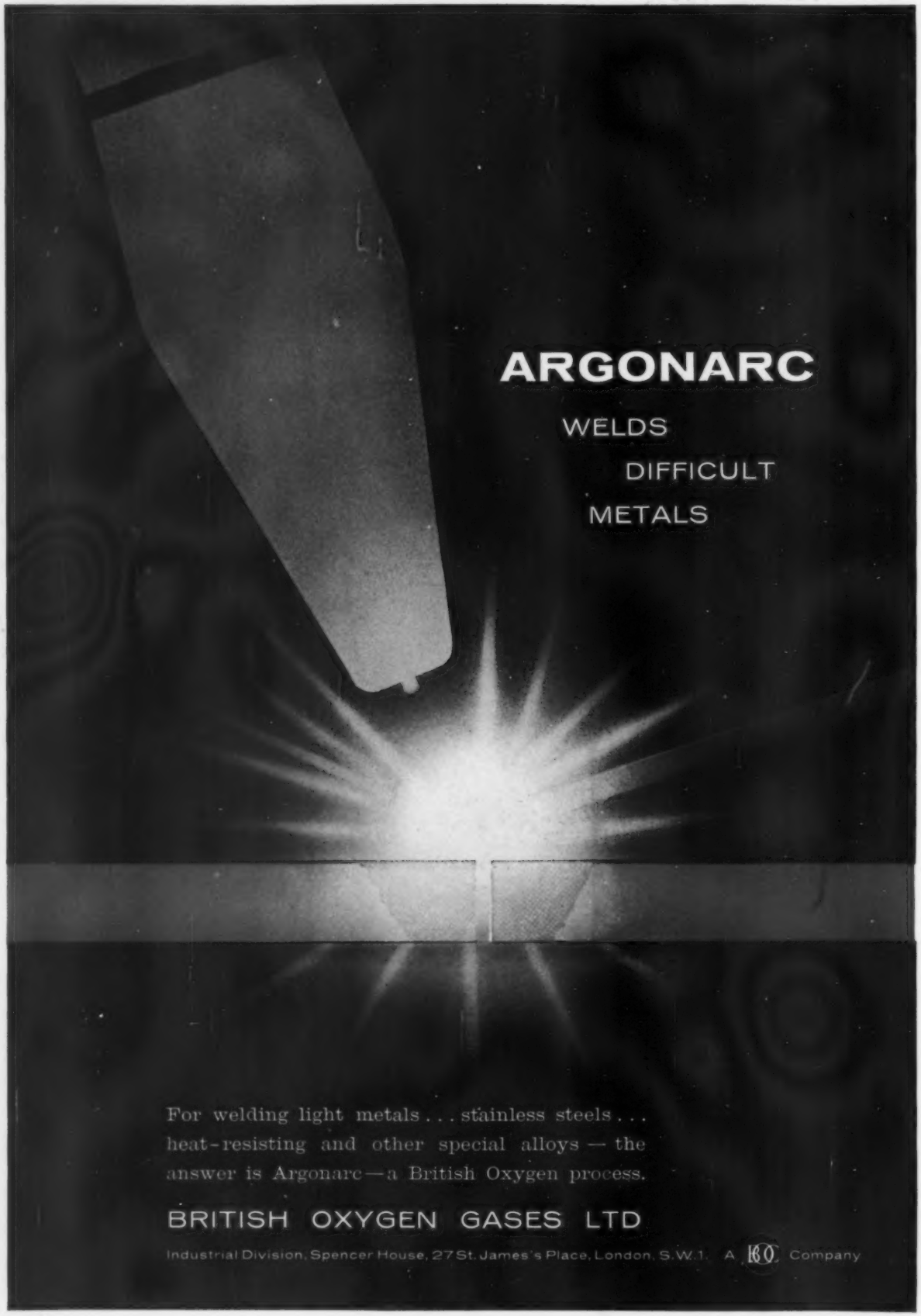
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